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Huć, Z., Kornek, E.

TAR POLLUTION IN THE FUEL THERMAL DECOMPOSITION PROCESS DURING THE LIGHTWEIGHT AGGREGATE PRODUCTION

(Powstawanie zanieczyszczeń smołowych w procesie rozkładu termicznego paliw podczas produkcji kruszyw lekkich)

Discussion of the mechanism of formation of tars on sinter belts during production of lightweight aggregates, with the description of physical and chemical properties of some tar grades, and the results of measurements of tar and dust pollution in the aggregate production for three manufacturing plants.

The lightweight aggregate industry has recently become one of the newest branches of the building materials industry. With the present level of the development of building industry, in view of a notable shortage of aggregates vast potentialities are expected from lightweight aggregate concretes. One of the major lightweight aggregates produced in this country is the aggregate obtained by sintering, or thermal expansion, of clayey materials on a sinter belts. During the thermal process off gases are released which contain dusts and tars in quantities that pose nuisance to the environment. For that reason, in the light of standing regulations the problem of the control of such gases emitted into the atmosphere, as well as a proper selection of efficient pollution control equipment, are of prime significance for the future of the lightweight expanded aggregate industry.

The recovery and composition of the tar produced depend upon the kind and rank of the fuel used, on how high is the temperature of the thermal decomposition process, and on the carbonization technique employed. Correct conclusions as to the effect of individual process variables on the tar composition cannot be easily made. An essential parameter is the technique itself, which is used to run the process, as the tar composition for the process conducted at the same temperature but by different techniques may vary. For instance, the initial temperature in the ignition furnace at the beginning of the sinter belt has no effect on the kind of tar produced. What is relevant here is the technique used, that is, the run of the process and the aggregate temperature in the sinter layer heated up by hot exhausts. During the clay sintering process with an addition of brown coal or coal shale in the production of lightweight expanded aggregates the temperature in the ignition furnace ranges from about 1100 to 1200°C. It could therefore be expected that the tar obtained is of the high-temperature kind; in fact a low-temperature grade is produced there. This is due to the fact that the charge traveling through the ignition furnace chamber gets heated merely in the top surface layer. The charge is then gradually cooled off on the belt and the exhausts released along with tar are discharged, owing to a reduced pressure set up under the furnace, into individual chambers and to the header. As the glow front in the furnace is of a temperature of 500 to 800°C and the zone depth amounts to ten or so millimeters, a decomposition process of the fuel contained in the feed takes place, which is referred to as low-temperature carbonization and is accompanied by the formation of low-temperature tar. The tar produced up to 500°C does not undergo pyrolysis on the sinter belt. The aggregate thus made, which is deprived of low-temperature tar, but which consists of the remainder of the mineral components, cools off. For that reason, results of the measurements for the above processes of the aggregate production are merely reported, and no attempts were made to compare them.

Given below are the correct pyrolysis temperatures for the common fuels used:

— wood and peat from 150 to 400°C,
— brown coal from 250 to 450°C,
— coal from 300 to 500°C,
— anthracite coal from 400 to 550°C.

In the low-temperature carbonization process first are released occluded gases, then decomposition water and gases, mostly carbon dioxide and carbon monoxide. At somewhat higher temperatures tar starts being produced, with a continuous rise in the formation of methane and hydrogen. The younger the fuel, the lower the temperature at which it starts decomposing and the lower the temperature at which the tar ceases to form. It may be admitted that the formation of low-temperature tar from lower rank fuels subsides in practice at 500°C or at most at 550°C. In exceptional cases some residual tar may still come above that temperature. The considerations given above refer also to coal shale; at 500°C the tar virtually stops forming on the sinter belt. Low-temperature tars are featured by a dark color, from dark brown to black, and at room temperature they are of a liquid to greasy consistency. These substances are of a characteristic smell. In Table 1 are gathered merely some of the physical properties of tars, as individual tars substantially differ in their properties, whereas their low chemical stability makes their full physical characterization difficult.

Table 1

Physical Properties of Low-Temperature Tars from Brown and Bituminous Coal

Type of tar	d g/cm³	C wt. %	H wt.%
Brown coal tar	0.90	85.30	11.20
Bituminous coal tar	1.05	82.30	9.10

Chemically the brown-coal and coal-shale low-temperature tar constitutes a mixture of paraffin hydrocarbons of the C7 to C32 range, olefins, and aromatics with side chains, as well as their oxygen derivatives and nitrogen derivatives with a substantial amounts of acid components (up to 25% of phenols). As opposed to high-temperature tar, the low-temperature tar contains naphthalene and anthracene in minor quantities. In addition to the elements specified in Table 1 (carbon and hydrocarbon) are also present nitrogen, sulfur, and oxygen. The latter three elements actually play an important role in the chemistry of tar formation. Unquestionably brown-coal tar contains sulfur compounds in larger amounts than do bituminous coal and bituminous shale tars. As the result of decomposition of such compounds hydrogen sulfide is produced. The sulfur content in low-temperature tar depends upon sulfur content in the original fuel and the way it is combined. For individual kinds of low-temperature tar sulfur content is given in Table 2.

Table 2

Sulfur Content in Brown and Bituminous Coal Tars

Type of low-temperature tar	S %
Brown coal tar	0.9–1.5
Bituminous coal tar	0.2–0.8

Low-temperature tars contain nitrogen in some quantities that attain 30 to 40% of total nitrogen present in the fuel from which it was made. The most nitrogen is found in the tars produced from brown and bituminous coals in which the nitrogen compounds largely occur as pyridine and its homologs. With increasing rank of fuel its cellulose content falls which initially results in an increased amount of phenols in the tar. Further increase in the rank associated with a decreased quantity of oxygen groups in the humins already brings about a drop in the phenol content of tar. During low-temperature carbonization of high-coal fuels the majority of low-temperature tars are formed from bitumens. For example, bitumens from peat yield 55 to 66% of the total tar obtained from that fuel; brown-coal bitumens afford above 70% tar. Thus the tar composition is to a large extent controlled by the nature of the bitumens present, that is, by the wax and rosin content in them.

Rosins provide low-temperature tar that contains terpene compounds in a quantity of 55 to 70%, whereas waxes yield this product comprising 35 to 60% paraffin. As concerns bituminous coal, sufficient data are lacking, as it is difficult to see a clear-cut between bitumens and humins; with increasing rank of coal bitumens turn into an insoluble form or they produce colloidal system during extraction.

It will be observed that low-temperature tars from low rank fuels contain not only fatty acids and phenols but they may have also saturated and unsaturated aliphatic and aromatic acids. The higher the rank of fuel from which tar was obtained, the less sensitive to temperature the tar is. Nevertheless, even bituminous coal tars undergo some changes upon distillation or extraction.

Elemental composition of the tar depends upon the feedstock. However, in any case the tar contains more hydrogen, much more elemental carbon, and much less oxygen than the feedstock. Elemental composition of some low-temperature tars compared with the composition of starting fuel is given in Table 3.

The yield of low-temperature tar from a variety of fuels as calculated per anhydrous and ashless matter is reported in Table 4. The values provided there refer to the low-temperature carbonization on a laboratory scale in a Fisher-Schroeder still.

The vast majority of tar produced in Poland (~90% of the total output) is the high-temperature product obtained largely in coke plants and, to a more limited extent, in gas plants. High-temperature tar is formed from aromatic compounds contained in low-temperature tar. Long side chains in molecules of the aromatic compounds contained in low-temperature tar break off to yield polynuclear compounds with short side chains. For that reason the composition of low-temperature tar differs substantially from the composition of high-temperature tar. In the process of carbonization of solid fuels during chemical processing of coal the formation of tar is a desirable phenomenon, as this product is a mixture of a wide variety of useful organic compounds.

On the other hand, in the production of lightweight expanded aggregates the formation of low-temperature tar is undesirable. Growth in the production of the aggregates of that kind has created the problem of treatment of the exhaust gases taken up from sinter belts to remove dust and tar contaminants.

Table 3

Elemental Composition of Some Low-Temperature Tars Compared with the Fuel Composition

Fuel and tar type	C %	H %	O %
Wood	~50	~6.1	~44
Wood tar	68–74	6.5–8.0	17–22
Brown coal	64–78	5–6	16–32
Brown coal tar	80–85	10–11.5	2.1–7.0
Bituminous coal	78–99	4.5–5	3.5–16
Bituminous coal tar	82–88	7.5–9.7	3.5–7.0

Table 4

Yield of Low-Temperature Tar Obtained from Various Fuels

Fuel	Yield %
Wood	10–24
Peat	9–22
Brown coal	5–27
Bituminous coal	3–17

The mechanism of formation of dust in this process is a separate question. In this study attention was focused merely on the presentation of results of the measurements of solid and tarry particulates in the aggregate production at the following three manufacturers: the Pruszków Aggregates Plant, the Bytom Lightweight Aggregates Plant, and the Siemianowice Plant of the "Haldex" Polish-Hungarian Company Inc.

In the Pruszków Plant a lightweight expanded aggregate, referred to as Glinoporyt, an expanded clay aggregate, is produced by sintering of the charge on sinter belt. During the measurement the charge was clay and brown coal in a quantity of $\sim 25\%$. Chemical composition of the roast gases was the following:

— CO_2 from 1.6 to 2.2%

— O_2 from 18.0 to 18.7%
— CO from 0.6 to 0.8%
— SO_2 ≈ 0.24 g/m³.

The water vapor content in dry gas was 16–20 g/m³, tar concentration — 0.5–1.63 g/m³, dust concentration from 0.5 to 0.81 g/m³. The exhaust gas temperature ranged from 50 to 70°C.

In the Bytom Lightweight Aggregates Plant an aggregate is produced which is referred to as Łupkoporyt. This expanded shale aggregate is made by sintering of coal shale on a sinter belt. The charge used for roasting consists of 85% of coal shale and 15% of sinter recycle. The elemental carbon content in the charge is about 9%.

The properties of the tar exhausted from over the belt were as follows:

— d^{20} — 1.011 g/cm³
— pitch — 63.0%
— ash — 0.29%
— distillation starts at 283°C, having distilled in 35.6% up to 350°C
— water — 5%
— insoluble matter in C_6H_6 — 1.65%
— softening point — 26°C.

Chemical composition of the roast gases was the following:

— CO_2 — 2.2%
— O_2 — 18.0%
— CO — 0.50%
— SO_2 — 0.10 g/m³.

The steam content in dry gas was 14 to 20 g/m³, tar concentration ranged from 1.11 to 2.25 g/m³, dust concentration from 0.34 to 0.70 g/m³. The exhaust gas temperature amounted to 35–58°C.

In the "Haldex" Polish-Hungarian Company Inc. an expanded shale aggregate is manufactured by sintering coal shale on sinter belt. Elemental carbon in the charge was 7 to 8%. Chemical composition of roast gases was as follows:

— CO_2 — 3.4%
— O_2 — 16.8%
— CO — 0.5%
— SO_2 — 0.1 g/m³.

Steam content in dry gas was 23–28 g/m³, tar concentration — 0.5–1.5 g/m³. The exhaust gas temperature ranged from 60 to 70°C.

As follows from results of the measurements shown above, the highest tar concentration in the roast gases occurs in the Bytom manufacture, amounting to 2.25 g/m³.

Both the tar concentration and dust concentration in the roast gases from sinter belts of the plants in the point were high. In Table 5 are given the values of dust and tar emission downstream of the belt as measured in the exhaust ducts.

Table 5

Values of Dust and Tar Emission Downstream of the Sinter Belt

Plant	Gas flow rate m^3/sec	Dust concentration* g/m^3	Dust emission g/sec	Tar concentration* g/m^3	Tar emission g/sec
Pruszków Aggregates Plant	22.2	0.81	18.00	1.63	36.2
Bytom Lightweight Aggregates Plant	36.7	0.71	25.7	2.25	82.6
Siemianowice "Haldex" Plant	20.0	—	—	1.5	30.0

*Maximum values.

The high values noted for dust and tar concentrations in the gases released into the atmosphere for all the manufactures examined pointed to the necessity of air pollution control measures to be taken with respect to those manufactures.

In the Bytom Plant two Hartman-type battery cyclones have been used for that purpose. This equipment, however, is inefficient, as this type is unsuitable for tar removal from exhaust gases. An additional problem in cyclone operation is its servicing needed to remove precipitated tar and dust from individual cyclone elements.

In the "Haldex" Manufacture an electrostatic precipitator was employed, but the unit is of low efficiency and poor availability factor.

On the other hand, no control device has so far been used in the Pruszków experimental establishment. The dust and tar concentration in that plant is measured with a setup composed of a Venturi tube, a foam scrubber and a fan. The tests performed on that setup demonstrated poor performance of the system. Hopefully, the control system will improve as a high-compression fan is provided. Mention should be made here that the studies performed so far on the use of wet collection systems for the treatment of roast gases proved inadequacy of these systems. Neither has a suitable method been developed for the emission control of roast gases produced during the manufacture of lightweight expanded aggregates, in view of a remarkable problem of the simultaneous occurrence of dust and tar in the exhausts.

Conclusions

The tar-removing equipment thus far employed in the lightweight aggregates industry is featured by poor efficiency and low availability factor. The reasons for that may be sought among insufficient knowledge of physicochemical properties and composition of the tars discharged, as well as the designing of industrial detarring systems without requisite tests and studies performed in semicommercial pilot plants.

REFERENCES

[1] Ryszka, E., "Pomiary zapylenia gazów w przewodach." (Measurement of Dust Concentration in Ducts). Wyd. "Śląsk," Katowice 1969.

[2] Zajączkowski, J., "Odpylanie w przemyśle." (Dust Control in Industry). Arkady, Warszawa 1971.

[3] Juda, J., Chruściel, S., "Ochrona powietrza atmosferycznego." (Atmospheric Air Conservation). WNT, Warszawa 1974.

[4] Juda, J., "Pomiary zapylenia i technika odpylania." (Dust Concentration Measurement and Dust Control Engineering). WNT, Warszawa 1968.

[5] Kowalenko, W., Mojsiejenko, J., Roszak, W., "Sztuczne kruszywa lekkie. Produkcja i zastosowanie." (Artificial Lightweight Aggregates. Their Manufacture and Uses). Arkady, Warszawa 1972.

[6] Haberski, A., "Fluidalne odgazowanie łupków przywęglowych zapobiega emisji smoły przy ich spiekaniu." (Fluidized Coal Shale Carbonization Prevents Tar Emission during the Shale Sintering Process) — Przegląd Nowości Hutnictwa, No. 4, 1975.

[7] Rago, B., Tomków, K., "Chemiczna technologia węgla." (Chemical Coal Technology). WNT, Warszawa 1971.

[8] Kornek, E., "Badania skuteczności działania stacji doświadczalnej oczyszczania gazów w COBR PKB w Pruszkowie." (Investigation of the Efficiency of the Emission Control Pilot Plant in the Pruszków Aggregates Plant). Unpublished study.

[9] Kornek, E., "Ekspertyza odnośnie emisji pyłu i smoły do atmosfery w Zakładzie "Haldex" Siemianowice." (A Survey on the Dust and Tar Emission in the Siemianowice "Haldex" Plant). Unpublished study.

[10] Huć, Z., "Ekspertyza z pomiarów emisji pyłowo-gazowych do atmosfery dla ZKL Bytom — II półrocze 1974 r. oraz I półrocze 1975 r." (A Survey on the Gaseous and Particulate Emission Measurements for the Bytom Lightweight Aggregates Plant for the Second Half of 1974 and the First Half of 1975). Unpublished study.

[11] Huć, Z., "Ekspertyza z pomiarów emisji pyłowo-gazowych do atmosfery — II półrocze 1975 r. oraz I półrocze 1976 r." (A Survey on the Gaseous and Particulate Emission Measurements for the Bytom Lightweight Aggregates Plant for the Second Half of 1975 and the First Half of 1976). Unpublished study.

Jagusiewicz, A., Mihułka, M.

PERFORMANCE CHARACTERISTICS OF THE POLISH MAKE SULFUR DIOXIDE ANALYZERS

(Charakterystyka techniczno-eksploatacyjna krajowych analizatorów SO_2)

Continuous measurements were carried out with the use of two prototype SO_2 analyzers developed in Poland. The two instruments were appraised on the basis of such characteristics as flow rate stability, zero stability, stability of the readings, response time, and sensitivity.

Sulfur dioxide ranks among the most deleterious, and emitted in large quantities, atmospheric pollutants. Its current emission rate in Poland amounts to 4.0–4.5 million tons per year [6] with an upward trend. The forecasts made recently provide an almost double increase in the sulfur dioxide emission volume by 1990 [6]. In this connection, the problem of the abatement of SO_2 emission constitutes one of the major issues in the light of ever-increasing requirements as to the environment engineering and environment conservation.

Research and development works conducted in this area follow essentially two lines. On the one hand, SO_2 emission control equipment is developed and installed; on the other hand, measurement and control instruments are made which are of improved design, possibly completely automatic, to determine emission rate and ground level concentration of this compound [1].

The domestic production of the measurement and control instruments for the SO_2 determination includes, in the first place, such instruments as AKZA-1 and ZAG from the Nonferrous Metals Industry Automation and Mechanization Works at Kęty, and Aspirator 334 released in a short demonstration lot by the UNIPAN Scientific Instruments Construction Experimental Division in Warsaw. These are actually air samplers rather than analyzers.

In recent years a few new prototype instruments have appeared

in this country for the continuous determination of emission rate and ground level concentration of sulfur dioxide. Of these are: EAS-1 and ALERT from the Kęty Works mentioned, and ANIM-75 launched by "Energopomiar" in Gliwice but available in limited quantities in view of its being manufactured in short lots, and an automatic SO_2 analyzer, whose prototype has been developed by the Institute of Environmental Engineering of Warsaw Technical University.

To determine the performance characteristics of the SO_2 analyzer prototypes of domestic manufacture, two instrument types have been tested at the Institute of Environmental Engineering, viz., ANIM-75, and SO_2 concentration meter, the latter developed by the Institute.

The principle of operation of the ANIM-75 analyzer is based on a coulometric reaction of sulfur dioxide with iodine dissolved in sulfuric acid. On the electrodes of the sensing cell of the instrument, which are

Measurement Data for

No. measurement	Day and hour of the measurement in July	Air sampling rate l/min	Deviation from chemical zero, 10-min periods mm	Zero deviation difference mm	Standard of the SO_2 diffusion μg/min	Weight of the cut-out peaks mg
1	2	3	4	5	6	7
	Series 1					
1	3—3 p.m.	0.2083	12-13	1	0.160	59.5; 55.6
2	3—7:30 p.m.	0.2033	12-13	1	0.160	65.5; 64.5
3	4—9 a.m.	0.2000	12-12	0	0.160	58.9; 62.3
4	4—7 p.m	0.197	11-12	1	0.160	45.6; 44.8
5	5—8 a.m.	0.197	10-10	0	0.160	55.0; 57.9
6	5—11 a.m.	0.191	10-10	0	0.160	56.8; 57.6
	Series 2					
7	12—9:35 a.m.	0.196	8-8	0	0.160	34.4; 32.8
8	13—8 a.m.	0.197	10-11	1	0.148	51.0; 52.8
9	13—6:35 p.m.	0.197	11-12	1	0.148	48.9; 57.6
10	14—8 a.m.	0.195	9-10	1	0.148	50.2; 51.6
11	14—12	0.198	10-10	0	0.148	59.4; 61.6
12	14—2 p.m.	0.200	10-11	1	0.148	52.4; 53.7
	Series 3					
13	24—11 a.m.	0.195	10-10	0	0.160	48.3; 45.9
14	25—7:30 p.m.	0.190	8-8	0	0.160	60.6; 57.2
15	26—9:05 a.m.	0.198	7-7	0	0.148	52.6; 55.0

anodically polarized, electrooxidation of iodine ions to free iodine occurs. The value of the current generated in the reaction is direct to the concentration of SO_2 in the air. This is a portable unit weighing 15 kg with the following performance characteristics:

— measurement range — 0–2 mg/m³
— accuracy of the readings — ±5%
— zero stability better than 1% per 24 hr
— response time — 5 sec
— delay time — 120 sec
— air sampling rate — 200 ml/min,

and is provided with a gauge that directly indicates SO_2 concentration. The instrument is insensitive to solid particulates, NH_3, F_2, and hydrocarbons.

The principle of operation of the automatic SO_2 analyzer designed

Table 1

ANIM-75 Analyzer

Peak weight equivalent 10^3 mg/m³	Reference time min	Specific concentration mg/m³	Conversion factor $k = \frac{C_w}{C_m} \cdot 10^{-3}$	Peak height h mm	Stability of readings $\frac{h}{C_w}$ $\frac{\text{mm}}{\text{mg/m}^3}$	Remarks
8	9	10	11	12	13	14
9.20	30	0.768	0.083	40	52.08	
10.73		0.787	0.073	40	50.82	
9.97		0.800	0.080	40	50.00	
7.65		0.812	0.106	43	52.95	
9.54		0.812	0.085	39	48.02	
9.98		0.837	0.063	40	47.78	
—		—	—	22 rejected	—	
8.78	30	0.750	0.085	32	42.67	$h_{av} = 39.0$
9.04		0.750	0.082	32	42.67	(0.160)
8.70		0.760	0.087	32	42.11	$h_{av} = 32.5$
10.13		0.750	0.074	32.5	43.33	(0.148)
8.83		0.740	0.084	33.0	44.59	
8.05	30	0.820	0.101	32	39.02	
10.33		0.842	0.081	38	45.13	
9.06		0.750	0.083	34	45.33	

by the Institute of Environment Engineering of Warsaw Technical University [3] is likewise based on the coulometric technique. Sulfur dioxide present in the gas under analysis is oxidized with bromine generated electrochemically. The change by an order of magnitude in the free Br_2 concentration brings about the corresponding variation in the potential of the cell. The current intensity of the Br_2 generator is a measure of SO_2 concentration in the gas under analysis. This instrument is of a stationary type with the following performance characteristics:

— measurement range — 0.1 mg/m³
— detectability limit — 0.026 mg/m³
— response time to abrupt concentration change ≤ 5 min
— zero drift — 20 μg/m³
— weight — ~ 50 kg.

Measurement Data

No. measurement	Day and hour of the measurement of July	Air sampling rate l/min	Deviation from chemical zero, 10-min periods mm	Zero deviation difference mm	Standard of the SO_2 diffusion μg/min	Weight of the cut-out peaks mg
1	2	3	4	5	6	7
	Series 1					
1	2—12:30 p.m.	0.1633	0–8	8	0.160	65.3; 65.7
2	2—2 p.m.		8–13	8		98.1; 92.8
3	2—8:30 p.m.		5–20	15		117.0; 114.6
4	4—8 a.m.		17–18	1		133.3; 141.6
5	4—3 p.m.		10–25	15		112.3; 112.6
6	4—7:50 p.m.		17–18	1		118.4; 117.0
7	5—9 a.m.		16–19	3		124.5; 120.2
	Series 2					
8	11—7:43 p.m.	0.1533	26–28	2	0.160	
9	12—8:03 p.m.	0.1666	35–40	1	0.160	
10	13—9:10 a.m.	0.1716	33–35	2	0.160	
11	14—9 a.m.	0.1683	32–34	2	0.148	
12	14—3 p.m.	0.1683	42–43	1	0.148	
	Series 3					
13	23—7:25 p.m.	0.1683	9–13	4	0.148	74.6; 74.4
14	24—10 a.m.	0.1700	20–30	10	0.160	157.9; 150.2
15	25—8 a.m.	0.1666	17–18	1	0.148	119.5; 113.6
16	25—2:15 p.m.	0.1566	16–19	3	0.148	62.6; 59.0
17	25—8:06 p.m.	0.1633	19–22	3	0.160	75.5; 70.0

The purpose of the comparative study was to make 14-day continuous measurements with the help of these analyzers so as to enable a comparison and appraisal of both instruments in terms of a few typical characteristics [5]. Of these typical characteristics were taken in the first place the following:

— air sampling rate,
— zero stability and stability of the readings,
— response time,
— interference factor,
— sensitivity of the instrument.

Moreover, personal contact with the instruments enabled a preliminary evaluation to be made in the aspect of its simple operation, modern design, and possible commercial lot production.

Table 2

for PW Analyzer

Peak weight equivalent 10^3 mg/m^3 8	Reference time min 9	Specific concentration mg/m^3 10	Conversion factor $k = \frac{C_w}{C_m} \cdot 10^{-3}$ 11	Peak height h mm 12	Stability of readings $\frac{h}{C_w}$ $\frac{mm}{mg/m^3}$ 13	Remarks 14
—	30	0.979	—	70 rejected	—	$h_{av} = 74.3$ (0.160) $h_{av} = 75.6$ (0.148)
19.45			0.050	59	60.27	
23.63			0.041	81	82.74	
28.05			0.034	80	81.72	
22.94			0.042	70	71.50	
24.02			0.040	77	78.65	
24.96			0.039	77	78.65	
						Series 2 rejected; unstable chemical zero, unstable temperature and great difference in readings
17.70	30	0.880	0.050	75	85.23	
30.20		0.941	0.031	80	85.02	
23.32		0.890	0.038	80	89.89	
12.94		0.940	0.072	72	76.60	
14.83		0.979	0.066	71	72.52	

With the aim to make a comparison of the performance features selected, three series of continuous comparative measurements of SO_2 concentration were performed using the two analyzer types on the basis of the following standards:

— standard B of gaseous SO_2 of a diffusion of 0.160 μg/min, developed by the Institute of Physical Chemistry and Technology of Warsaw Technical University;

— Philips gaseous SO_2 standard of a diffusion of 0.148 μg/min.

As a reference the Philips standard was taken.

Peak heights and peak areas were used in the calculation of SO_2 concentrations, like in gas chromatography. This was possible, as both the instruments are equipped with paper tape records and the tape rate was constant and equal to 2 cm/hr for the two units.

Of the several techniques of the measurement of peak area the method of weighing of cut out peaks was adopted as this method facilitates the area determination of distorted or otherwise poorly developed peaks. Detailed data from the measurements made for both analyzers are reported in Tables 1 and 2.

Sampling Rate Stability

In accordance with the performance characteristics provided by the designers, the air sampling rate should equal ~12.0 l/hr (0.2 l/min) and ~10.01 l/hr (0.167 l/min) for ANIM-75, and PW* analyzers, respectively. Meanwhile the comparative measurements of air sampling rate in both instruments performed for a period of ten or so days revealed discrepancies with the specifications supplied by the designers. To be more specific, for ANIM-75 analyzer the air sampling rate ranged from 0.191 to 0.208 l/min, which corresponds to 11.8 to 12.2 l/hr, whereas for PW analyzer the values were 0.1533 to 1716 l/min or 9.4 to 10.4 l/hr. Thus the values differ from the specifications for extreme cases by nearly 2% for ANIM-75 instrument and by 6% for PW analyzer. Measurements of the air sampling rate were carried out with a rotameter connected in series with the instrument (cf. column 4, Tables 1 and 2).

Readability

The concept of readability is related to the peak height drawn by both the instruments for the measurement series with the use of the same standard. The evaluation was made on the basis of inspection of the data in column 12 of Tables 1 and 2. The average reading values for both the standards used are set up in columns 14. It follows that readability is higher in the PW recorder than it is for the ANIM-75 recorder, as 1 mm of the reading corresponds to nearly half as high concentration as in the ANIM-75 instrument (for the PW standard this factor is 1.9, whereas for the Philips standard it is 2.3). Furthermore, the recorder tape width in ANIM-75 analyzer is 10 cm, whereas in PW instrument it is 12 cm, and the tape rate is the same for both units and equal to 2 cm. It should be pointed out, that a very thick line drawn by the recorder pen of ANIM-75 instrument may substantially bear upon the sensitivity of the apparatus in the very low concentration range.

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*PW stands for Warsaw Technical University.

Zero Stability

Zero stability is the variation in the instrument reading under a constant concentration of 0.00 mg/m^3, continuous flow of the gas and solution, and with other established conditions such as temperature or pressure within 24 hours. Zero stability test was carried out by analyzing reaction of both instruments to the sulfur dioxide content in the laboratory room. Thus a zero concentration of this compound was assumed inside the Institute building located on the outskirts of the city and surrounded with a fairly wide strip of greens that insulates the place from the urban development.

ANIM-75 analyzer confirmed this assumption, as its recorder pen drew a thick and straight baseline to coincide with the zero marking on the tape. On the other hand, PW analyzer showed a minor concentration value that oscillated about the zero line. This observation may point to a better zero stability of ANIM-75 instrument but, at the same time, it may be indicative of a higher sensitivity of PW unit. The latter conclusion is supported by the fact of better readability with PW analyzer and too thick a recorder line drawn by the ANIM-75 recorder that graphically averaged out the baseline. The actual reason for the discrepancies observed could be conclusively resolved merely with additional test measurements of SO_2 concentration in the laboratory room carried out, for instance, by the classical West-Gaeke method.

Stability of the Readings

The method of weighing of the peak areas cut out from the paper tape recordings was employed to obtain a correct evaluation of the concentration values recorded by the two analyzer types to eliminate the errors due to instability in air sampling and differing width of the recorder tapes of the instruments compared. To do this, xerox copies were taken of the recordings to eliminate the weighing error, since the xerox paper was of the same substance and of the same moisture content. The peak weight equivalent and the conversion factor k had to be introduced for the purpose of the quantitative analysis of SO_2 concentration by the method employed.

Calculations were made using the following formulas

$$C_m = \frac{m}{ut} 10^3 \tag{1}$$

where

C_m — the peak weight equivalent, mg/m^3,
m — the peak weight, mg,
u — the air sampling rate, l/min,
t — the measurement time, min.

$$C_w = \frac{m_w}{u} \tag{2}$$

where

C_w — specific concentration, mg/m^3,
m_w — the weight of the standard related to the unit time, μg/min.

$$k = \frac{C_w}{C_m} \tag{3}$$

where k is the conversion factor of the peak weight equivalent.

Relation between C_w and C_m is given by equation

$$C_w = kC_m \tag{4}$$

The introduced conversion factor k ranges as follows:

For the 0.160 μg/min standard:
— ANIM-75 analyzer
$k = 0.073 \cdot 10^{-3}$ to $0.106 \cdot 10^{-3}$
— PW analyzer
$k = 0.031 \cdot 10^{-3}$ to $0.066 \cdot 10^{-3}$

For the 0.148 μg/min standard
— ANIM-75 analyzer
$k = 0.074 \cdot 10^{-3}$ to $0.087 \cdot 10^{-3}$
— PW analyzer
$k = 0.038 \cdot 10^{-3}$ to $0.072 \cdot 10^{-3}$

As can be seen, considerable differences occur in the k values for both analyzers (cf. column 11 of Tables 1 and 2).

Specific concentrations, obtained from the three measuring series mentioned in terms of the peak weight equivalent and its conversion factor *k*, are gathered in column 10 of Tables 1 and 2.

To determine stability of the readings an additional column 12 is provided (Tables 1 and 2) which presents the quotient of the peak heights *h* and specific concentration. According to definition, stability of the readings is the variation in the instrument reading under a constant concentration and at a constant flow rate of the gas and solution. In view of some variations of the flow rate, specific concentration C_w failed to attain a constant value, and only the quotient h/C_w could be used for a direct estimation of the results obtained. The estimation was related separately for both sulfur dioxide standards used, by calculating standard deviation [4] by means of the sum of square deviations from expression

$$\sigma = \sqrt{\frac{1}{n-1}\Sigma(d_i-\bar{d})^2} \tag{5}$$

Table 3

Statistical Estimation of Stability of the Readings of Instrument ANIM-75

Standard of the SO_2 diffusion $\mu g/min$	No. measurement	Stability of readings $d = h/C_w$ $\frac{mm}{mg/m^3}$	Arithmetic mean of stability $\bar{d}$ $\frac{mm}{mg/m^3}$	Deviation $(d-\bar{d}) = \Delta$	Δ^2	Standard deviation σ	Confidence interval
1	2	3	4	5	6	7	8
0.160	1	53.08	48.22	4.75	22.56	4.89	48.22±4.10
	2	50.82		3.49	12.18		
	3	50.00		2.67	7.13		
	4	52.95		5.62	31.58		
	5	48.02		−0.20	0.04		
	6	47.78		−0.44	0.20		
	13	39.02		−9.20	84.64		
	14	45.13		−3.09	9.55		
		385.80			167.88		
0.148	8	42.67	43.45	−0.78	0.61	1.25	43.45±1.31
	9	42.67		−0.78	0.61		
	10	42.11		−1.34	1.80		
	11	43.33		−0.12	0.01		
	12	44.59		1.14	1.30		
	15	45.33		1.88	3.53		
		260.70			7.86		

$t/n^{1/2}$ after the Student distribution at a significance level of 0.95.

where

σ — standard deviation,
$\bar{d}$ — the mean of quotient h/C_w,
d_i — the value of the quotient in the measurement series,
n — the number of measurements in the series.

Results of the calculations of standard deviation are gathered for individual measurement series in column 7 of Table 3 (ANIM-75) and of Table 4 (PW analyzer).

On the other hand, the error related to the stability of the readings of both instruments was found from relation

$$\sigma \frac{t}{n^{1/2}} \tag{6}$$

where $t/n^{1/2}$ is taken from the Student distribution tables for a definite significance level.

Results of the calculations for a significance level $(1-\alpha) = 0.95$ are presented in column 8 of the above mentioned tables. It follows that for

Table 4

Statistical Estimation of Stability of the Readings of Instrument PW

Standard of the SO_2 diffusion $\mu g/min$	No. measurement	Stability of readings $d = h/C_w$ $\frac{mm}{mg/m^3}$	Arithmetic mean of stability $\bar{d}$ $\frac{mm}{mg/m^3}$	Deviation $(d-\bar{d}) = \Delta$	Δ^2	Standard deviation σ	Confidence interval
1	2	3	4	5	6	7	8
0.160	2	60.27	76.38	−16.11	259.53	8.03	76.38 ± 6.75
	3	82.74		6.36	40.45		
	4	81.72		5.34	28.52		
	5	71.50		−4.88	23.81		
	6	78.65		2.27	5.15		
	7	78.65		2.27	5.15		
	14	85.02		8.64	74.65		
	17	72.52		−3.86	14.90		
					452.16		
0.148	13	85.23	83.91	1.32	1.74	6.74	83.91 ± 16.72
	15	89.89		5.98	35.76		
	16	76.60		−7.31	53.44		
					90.94		

$t/n^{1/2}$ after the Student distribution at a significance level of 0.95.

both kinds of standards higher stability of the readings is for ANIM-75 instrument, for which the respective values are:

— PW standard (0.160 μg/min) — 48.22 ± 4.10,
— Philips standard (0.148 μg/min) — 43.45 ± 1.31.

The PW analyzer instead showed, respectively:

— PW standard — 76.38 ± 6.75,
— Philips standard — 83.91 ± 16.72.

For the technique of the determination of stability of the instrument readings, the error for the PW analyzer may be potentially always larger, as the peak height, hence also the *k* factor, for that instrument is twice as high.

Response Time

Response time is defined as the time interval between the instant at which the concentration at the outlet changes abruptly, and the instant of the initial discernible change in the instrument reading. Both analyzer types responded equally rapidly to the standard concentration and in each of the three measurement series conducted a distinct rise in the peak height could be noticed after 60 sec. This time can therefore be regarded as the response time for both the analyzers tested.

Interference Equivalent

As results from the specifications and operation manual of both the instruments, ANIM-75 analyzer is insensitive to dust contaminants, No_x, NH_3, F_2 and hydrocarbons, whereas the PW model is insensitive primarily to O_3 or H_2S. Irrespective of the actual selectivity of one or the other instrument it appears that the interfering substances during the coulometric determination of sulfur dioxide with iodine or bromine should be the same. However, a random check on both the analyzers for presence of interfering agents such as NO_x or H_2S failed to give satisfactory results. Both the instruments used to respond to the presence of the above compounds as increased or dropped value of the concentration measured.

Under these conditions a more representative test should be executed for selectivity of the method with the use of some standards that would unambiguously determine the interfering agents. Only the measurements carried out in that way will enable the interference equivalent to be calculated for other contaminants, and expressed as mg/m^3 SO_2. Irrespective of this requirement, a correctly working analyzer should be equipped with a selective SO_2 filter provided with additional heating system to ensure stabilization of the filter temperature.

Another filter kind provided as a basic equipment of the analyzer should be a dust filter. This is needed, as the dust settled on the air sampling ducts absorbs SO_2 thereby distorting result of the determination. This filter, like the previously discussed one, should also be heated to a temperature of 100°C and should be equipped with a system that would stabilize its temperature. A filter of a correct design manufactured in this country is, for instance, filter A packed with glass wool and heated to 100°C. This filter is provided in the PW analyzer.

Efficiency of filter A, as well as of filter B also incorporated in the design of the PW analyzer, was, however, limited on account of their being worn out. As follows from the information of the designer, the filters have been in operation for over two years and have not been regenerated yet. It remains to be explained, however, why the coulometric method adopted in the ANIM-75 instrument, based on the reaction of SO_2 with iodine, is claimed to be insensitive to interfering agents, although the analyzer has none of the filter kinds required.

Sensitivity

Sensitivity of the analyzer is determined as the least variation in SO_2 concentration at the inlet that brings about a readable change in the instrument reading. It follows from the measurements made that the instruments tested differed in the sensitivity thus defined. Specifically, these differences were:

Analyzer ANIM-75

— for the standard of a diffusion of 0.160 μg/min and an average for a given measurement series inlet concentration $C = 0.809$ mg/m^3 and an average peak height $h_{av} = 39$ mm measured, it showed a sensitivity of 0.020 mg/m^3;

— for the standard of a diffusion of 0.148 μg/min, and an average inlet concentration $C = 0.750$ mg/m^3 for a given measurement series and an average peak height $h_{av} = 32.5$ mm measured, it showed a sensitivity of 0.023 mg/m^3;

Analyzer PW

— for the standard of a diffusion of 0.160 μg/min and an average inlet concentration $C = 0.974$ mg/m^3 for a given measurement series, and an average peak height $h_{av} = 74.3$ mm measured, it showed a sensitivity of 0.013 mg/m^3;

— for the standard of a diffusion of 0.148 μg/min and an average inlet concentration $C = 0.903$ mg/m^3 for a given series of measurements.

and an average peak height $h_{av} = 75.6$ mm measured, it showed a sensitivity of 0.011 mg/m^3.

The values reported above are, therefore, to be meant that to a readable change in concentration as noted on the recorder chart of the instrument (one mark equals 1 mm on the chart) corresponds a definite inlet SO_2 concentration which is on the average 0.0215 mg/m^3 for ANIM-75 instrument and 0.012 mg/m^3 for PW instrument.

Easy Operation

ANIM-75 analyzer is undoubtedly easier in operation in view of its case and external finish being given the form of a market product. The prototype case of PW analyzer makes this instrument sensitive to transport; the unit is bulky and therefore more suitable for stationary rather than portable use.

The use of integrated circuits in the integrator amplifiers would greatly reduce the size of the instrument. The fact that the recorder is placed outside the apparatus in the ANIM-75 model may be an advantage in case of remote measurements with the recorder installed in a building like a laboratory. This is a disadvantage, however, in case of field work.

Modernity Standard

Both analyzer types meet the current modernity standards as they use the coulometric method based on the reaction of sulfur dioxide with bromine or iodine dissolved in sulfuric acid. Likewise the finish of ANIM-75 analyzer has an attractive appearance.

On the other hand, selectivity of the method itself is inadequate. As mentioned previously, ANIM-75 model is not provided with suitable filters, whereas PW analyzer was equipped with filters of poor efficiency which failed to ensure the expected selectivity of the method. Application of integrated circuits in the PW model will also affect favorably its quality, thus also its modernity standard, and will substantially reduce size of the apparatus.

Prospects for Lot Production

The ANIM-75 analyzer is undoubtedly of a more advanced design which makes it more fit for the commercial production. Prior to the final decision, however, the problem of selectivity of the instrument should be made clear by making tests on the standards of basic interfering agents.

One more favorable factor to be scored to ANIM-75 analyzer is the price of the unit set at 50,000 zlotys by the manufacturer. The cost of the PW model, on the other hand, is rather vague and, estimated by the designer, may approach 120,000 zlotys. Moreover, the PW model necessitates in the first place the finish and casing to be worked out which, expectedly, should be quite attractive with the use of integrated circuits; of other things to be done is the replacement of the filters and a check on their selectivity.

Conclusions

On the basis of the 14-day measurements performed according to an established code of the comparative criteria and appraisal of the two analyzer models the following can be said:

1. ANIM-75 analyzer is an advanced design model featuring better sampling rate stability, stability of the readings, and zero stability. The model therefore shows promise for a preferential lot production. Prior to the decisions relevant to this question, however, the following should be done:

— comprehensive check of the analyzer on the selectivity of the coulometric reaction of sulfur dioxide with iodine dissolved in sulfuric acid,

— improvement of readability of the instrument by the use of finer-point recorder pen,

— provide for a model variant with the built-in recorder,

— sampling rate should be made more stable,

— zero drift should be checked following the improvement in readability.

2. PW analyzer is actually a prototype design and necessitates further work to be done. The work should be focused primarily on the following:

— improved stability of the readings,

— full stability of sampling rate,

— improvement of the modernity of the design by the use of integrated circuits with the subsequent reduction of the instrument size,

— more attention to the design of the casing and finish,

— check on selectivity of the instrument upon previous replacement of the filters A and B worn.

An advantage of the model is its high sensitivity and high readability.

3. Both models, following the elimination of the shortcomings and insufficiencies noted, may be used for the measurement of GLC of sulfur dioxide particularly in the concentration range close to the currently

standing standards of threshold limit values for both daily average and 20-min average levels.

4. On account of the shortage of adequate measurement and control instruments on the domestic market for the air pollution control monitoring and the notable import problems in this field, the work on a more perfect development of the design of both models should be considered of vital importance. Thus, research work should be undertaken by the relevant companies along these lines.

REFERENCES

[1] Strojek, J., Uziel, Z., Żak, J., "Analizatory do oznaczania SO_2 w gazach." (The SO_2 Analyzers for Gases) — Chemia Analityczna, Vol. 18.

[2] "Instrukcja obsługi analizatora ANIM-75." (Operation Manual for ANIM-75 Analyzer). "Energopomiar" Research and Measurement Works of Power Industry, Gliwice.

[3] "Urządzenie do automatycznego pomiaru SO_2 w powietrzu atmosferycznym." (A Device for Automatic Measurement of SO_2 in the Atmospheric Air). Institute of Environmental Engineering, Warsaw Technical University. Unpublished study.

[4] Eckschlager, K., "Błędy w analizie chemicznej." (Errors in Chemical Analysis). PWN, Warszawa 1972.

[5] "Tlenowe związki siarki i ich oznaczanie w powietrzu atmosferycznym i emitorach." (Oxygen Sulfur Compounds and Their Determination in the Atmospheric Air and in Emitters). Proceedings of the Symposium, Katowice, October 25–26, 1973.

[6] "Prognoza emisji zanieczyszczeń na 1990 rok." (Pollution Forecast for 1990). The Expert Panel of the Polish Association of Sanitary Engineers and Technicians of the Federation of Engineering Associations (NOT). Warszawa 1973.

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THE THREE-PHASE COUNTERCURRENT FLUIDIZED-BED TECHNIQUE FOR GASEOUS EMISSION CONTROL

(Odpylanie gazów metodą fluidyzacji trójfazowej przeciwprądowej)

The three-phase countercurrent fluidized-bed technique is described in its application to the treatment of gaseous emissions, with suitable formulas for the calculation of the devices used for that process.

Turbulent contact absorbers, which may alternatively be termed spray fluidized-bed scrubbers, had been patented in 1958 by Alvin W. Kielback in the United States, but as soon as 1959 such scrubbers came to be used by Aluminium Company of Canada, Ltd. for the treatment of effluent gases exhausted from Soederberg cells used in the electrolytic manufacture of aluminum from alumina. The gases, which contain hot hydrogen fluoride, and fluorine compounds, aluminum compounds, tar, carbon, etc., the particulate emissions being below 1 μm in size, were treated in six scrubbers of a capacity of 100 f^3/min (Fig. 1). The hydrogen fluoride absorption was attained in excess of 95%, and dust collection efficiency in a range from 95 to 100% at a pressure loss of some 100 mm H_2O [1]. Ever since the scrubbers of that kind find increasing application in mass transfer processes, especially when the liquid is contaminated with solids, as a remarkable advantage of these apparatuses is their self-cleaning ability of the bed.

A schematic diagram and principle of operation of the scrubber is illustrated in Fig. 2. The packing is accommodated on the bottom retaining grid. The grid is designed to support the packing and to divide the gas stream. Te percentage of the free surface area of the grid ranges typically from 35 to 45%.

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The top retaining grid restricts the dynamic height of the packing, and prevents possible entrainment of the packing by the gas. In multistage scrubbers the top grid constitutes additionally the bottom grid of the following stage. Percentage of the free surface area of the top retaining grid is usually 90%. The openings in the grids may be round or rectangular. The packing is typically in the form of solid or hollow balls of low density. The balls used to date have been 3 to 40 mm in diameter. A condition for a correct operation of the apparatus is that the following relations be satisfied: $D/d_b > 10$ and $d_b > d_o$. The author of study [2] found out experimentally that equally good are other types of packing like Białecki rings or Raschig rings.

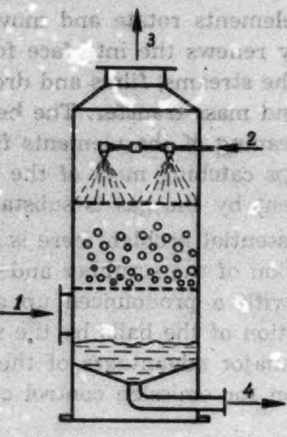

Fig. 2. A schematic of the spray fludized-bed scrubber: *1* — dirty gas feed; *2* — sprawy liquor feed; *3* — clean gas to liquid separator; *4* — spray liquor supply.

Fig. 1. The spray fluidized-bed scrubber used to control emissions from the Soederberg alumina cells.

Operation of the scrubber is based on the process of the three-phase countercurrent fluidized-bed absorption.* The scrubbing liquor is fed through a sprayer accommodated above the top grid and flows gravitationally downwards. Dirty gas, on the other hand, is delivered under the bottom grid, it flows through the grid openings, being divided into a multiplicity of streams, and subsequently makes its way between the packing elements. Because of the spraying the gas flow through the packing bed is obstructed which, in consequence, results in making the packing elements rotate and move upwards. The turbulence of the bed constantly renews the interface formed by the packing surface, and surfaces of the streams, films and drops, which greatly promotes the process of heat and mass transfer. The bed turbulence, at the same time, results in self-cleaning of the elements from solid particles. Finally, this turbulence helps catching most of the liquid drops owing to which the liquid entrainment by the gas is substantially reduced.

An essential problem here is also a uniform spraying over the entire cross section of the scrubber and its wall to prevent overcrowding of the packing with a pronounced up and down motion of its top layer and accumulation of the balls by the scrubber wall.

The major advantages of the spray fluidized-bed scrubbers in their application for emission control compared with conventional apparatuses are:

— the ability of the bed to self-cleaning,
— high efficiency,
— possible operation under high flow rates of gas and liquid, which entails reduced size of the scrubber,
— possible operation over a wide range of gas and liquid flow rates,
— no mechanically driven parts,
— easy operation and maintenance,
— economic operation.

A certain drawback of these devices is a high consumption of the liquid unless recycling is feasible.

A correct operation of the scrubber of this type depends upon a proper selection of both the dimensions and hydraulic parameters. Of the dimensions that essentially affect the operation are: inside diameter of the scrubber, grid spacing, free surface area of the retaining grid, as well as density, size, and static depth of packing. The hydraulic quantities include gas flow rate, spraying rate, gas and liquid holdup, and the dynamic depth of packing. Interrelations of the hydraulic and dimensional parameters inclusive of the method of their calculation are given below.

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*There are also scrubber types with bottom feed of scrubbing liquor, i.e., those working on the principle of three-phase countercurrent-cocurrent fluidized-bed absorption, units with horizontal turbulence of the packing and mixed types (e.g., first stage is Venturi absorber, second stage is the three-phase countercurrent fluidized-bed absorber).

In view of the advantages of the scrubbers of this type detailed above, they are increasingly gaining in popularity worldwide. A number of investigations have been made of both a qualitative nature and on hydrodynamics of the three-phase fluidization process.

Gas flow rate through the scrubber affects the condition of three-phase fluidization process. In the range 1 to 4.5 m/sec related to the empty cross section of the apparatus three various stages of fluidization process could be observed [3], [4]. The first initial stage of the process starts when the gas flow rate overcomes the critical flow rate value w'_{crit}, when the packing expands and grows to the height of the dynamic depth H_D well above the value of the static depth of the packing at idle, H_{stat}. In this first stage only the balls from the central section of the apparatus rise, and fall by the wall. In this connection this stage has been referred to as the fountain stage. With a further rise in gas flow rate an intermediate stage sets in. In this stage the balls from the area next to the wall start moving toward the scrubber center, thus to the middle of the gas stream. However, they never reach the fountain but are lifted not very far from the wall to fall down soon. The full fluidization stage is attained at a definite flow rate w'_{crit} which is different for every value of spraying rate. In this stage the balls from the wall zone expand, all the balls become fluidized, and the gas stream is uniformly divided over the entire cross section of the column.

Authors of papers [5]–[7] do not confirm from their own studies the presence of the intermediate stage but they claim that the system becomes fully fludized as soon as the w'_{crit} value of the initial stage is overcome. In the initial stage merely part of the liquid in the middle section of the apparatus is in a fluidized state, while the remainder of the liquid flows down along the immobile layer of the balls near the wall, thus not getting in contact with the gas. The optimum operation of the scrubber is the condition of full fluidization. However, at too high a gas flow rate ($w > w_f$) part of the packing elements adhere to the top grid and bring about flooding of the apparatus. Based on their investigations authors of papers [3], [4], [6]–[8], [11] derived a number of formulas for the calculations of critical gas flow rates. The formulas are gathered in Table 1. The applicable range is reported in Table 4.

Proper operation of the apparatus also depends upon the quantity of liquid held up by the retaining grid and by the packing. The formulas for the holdup of the scrubbing liquid are collected in Table 2.

Table 1

Critical Gas Velocities, m/sec

Definition of the critical gas velocity	Formula	Remarks	Reference
Minimum fluidization velocity, w_{min}	$\mathrm{Re}_{min} = 142\left(\delta\frac{\varrho_b}{\varrho_l}\right)^{0.33}\left(\frac{d^*}{d_b}\right)^{-2.2}\cdot$ $\cdot\exp\left[-7.3\cdot10^{-6}\left(\frac{\varrho_b}{\varrho_l}\right)^{-0.33}\left(\frac{d^*}{d_b}\right)^{1.14}\mathrm{Re}_l\right]$	$\mathrm{Re}_{min} = \frac{w_{min} d_b \varrho_g}{\eta_g}$ $\mathrm{Re}_l = \frac{4G_l}{3600\, a\eta_l}$	[7]
Transition velocity to full fluidization stage, w_{crit}	$\frac{w_{crit}^2 a}{g}\frac{\varrho_g}{\varrho_l} = 8\delta^{1.5}\left(\frac{\varrho_b}{\varrho_l}\right)^{0.64}\cdot$ $\cdot\exp\left[-4\left(\frac{G_l}{G_g}\right)^{0.25}\left(\frac{\varrho_g}{\varrho_l}\right)^{0.125}\right]$		[7]
Maximum permissible gas velocity, w_d	$w_d = 2.9\delta^{0.4}\left(\frac{\dot{V}_l}{\dot{V}_g}\right)^{-0.15}$	accuracy of the formula is ±10%; the velocity is calculated for the cross section of the empty apparatus	[4]
Flooding rate, w_f	$w_f = w^*_{min}\left[\frac{H-(1-\varepsilon_o)H_{stat}-h_{st}}{1.16\,\varepsilon_o H}\right]^3$	$\varepsilon_o = 0.385\left(\frac{d^*}{d_b}\right)^{-0.07}$ w^*_{min} was calculated from formula (1) in Table 1 for $\mathrm{Re}_l = 0$	[7]
Permissible gas velocity, w_d	$w_d = w^*_{min}\left[\frac{H_D-(1-\varepsilon_o)H_{stat}-h_{st}}{1.16\,\varepsilon_o H_D}\right]$	$\varepsilon_o = 0.385\left(\frac{d^*}{d_b}\right)^{-0.07}$ w^*_{min} was calculated from formula (1) in Table 1 for $\mathrm{Re}_l = 0$	[7]

The range examined is specified in Table 4.

Table 2

Liquid Holdup in the Apparatus

Definition	Formula	Unit	Remarks	Reference
The holdup per 1 m^3 of volume of the apparatus, V_v	$V_v = 4.605\cdot 10^{-3} G_l^{0.6} d_b^{-0.5} + 0.2$	m^3/m^3		[8]
The holdup in the mobile bed, V_w	$\frac{4V_w}{\pi D^2} = 2.3\cdot 10^{-3} L^{0.5} H_{stat}^{0.75} d_b^{-0.6}$	m^3	the formula ignores the holdup on the grid under full fluidization	[4]
The weight of the liquid held up per 1 m^2 of area, m_{hl}	$m_{hl} = A d_b^{-0.28} H_{stat}^{B}$	kg/m^2	at $H_{stat} \geqslant 0.05$ m : $A = 284$; $B = 1$ at $H_{stat} < 0.05$ m : $A = 586$; $B = 1.26$ accuracy of the formula ±10%	[10]
The liquid holdup, V_{hl}	$V_{hl} = h_{hl} F = C\left[\left(\frac{G_l}{G_g}\right)^2 \cdot \frac{\varrho_g}{\varrho_l}\right]^{k+1} \cdot \frac{\Delta p_e}{\varrho_l g} F$	m^3	under initial fluidization stage $C = 0.05, \quad k = 0.8$ under full fluidization stage $C = \frac{5.36\cdot 10^{-2}}{\delta^3} \cdot \frac{d^*}{d_b}\left(\frac{\varrho_b}{\varrho_l}\right)^{-0.74}\left(\frac{G_l}{G^*}\right)^2$ $k = \frac{1.58}{\delta^{-0.16}}\left(\frac{d^*}{d_b}\right)^{-0.1}$	[7]
The holdup in the mobile bed, V_w	$\frac{4V_w}{\pi D^2} = 17.1\cdot 10^{-4} L^{0.75} w^{0.95} d_b^{-0.33} H_{stat}$	m^3	the formula is valid for the range $w = 1$–3.5 m/sec $L = 31.15$–124 m^3/m^{2}hr	[9]

Another factor that impairs efficiency and performance of the spray fluidized-bed scrubbers is entrainment of liquid by the gas stream. Actually the entrainment is insignificant compared with other type wet collection devices because of a good separating ability of the fluidized bed. This ability may additionally be improved by the use of rough instead of smooth balls.

However, the authors of study [9] argue that at flow rates of gas above 3 m/sec mist eliminators should be used. The same investigators observed a substantial decrease in the entrainment effect from their study on the hydraulics of the three-phase fluidization with balls of variable density. They found that an addition of some balls of a density approaching that of the liquid to the regular packing of balls of lower density compared with the liquid, prevents the formation of heavy mist, as the gas bubbles break on the surface of the mobile packing and the fact that light balls are pushed out upwards on the surface, reducing thereby the quantity of the liquid entrained. Formulas for the calculation of relative percent entrainment *e* are reported in studies [12] and [13]. For the air/water system authors of study [12] deriveid the formula

$$\log e = 0.39 - 0.013\, L \frac{G}{9H - 1.47} \log \left(\frac{w}{4}\right)^{4.38} \tag{1}$$

whose accuracy varies from 12 to 15%, while for any system

$$e_r = e\left(\frac{\eta + 5}{6}\right) \cdot (1 - 0.6\, \Delta\varrho) \cdot \left(\frac{w}{4}\right)^{4.38\,(1 - 1.18\,\Delta\varrho)} \tag{2}$$

where

e — relative entrainment of water,
e_r — relative entrainment of liquid,
η — viscocity of the solution, cP,
$\Delta\varrho$ — $\varrho_s - \varrho_w$, g/cm^3,
ϱ_s — density of solution
ϱ_w — density of water,
w — gas velocity, m/sec.

The performance of the operation and the working height of the apparatus H are directly affected by dynamic depth of packing H_D. Optimum working conditions are achieved if the following condition is met: $H = (1.1 \text{ to } 1.2)\, H_D$. Formulas for the calculation of H_D are reported in ref. [4], [6], [7], [11], [13], and [17]. The most convenient is the formula derived in [11]

$$H_D = 0.08\, L^{0.3} H_{stat}^{0.6}\, w_0^{0.92};\ \text{m} \tag{3}$$

Table 3

Gas Flow Resistances in the Apparatus

Definition	Formula	Remarks	Reference
Total flow resistances under full fluidization Δp, kg/m²	$\Delta p = \Delta p_{gs}+\Delta p_{\sigma}+\Delta p_{ws}+\Delta p_{lw} = \Delta p_{ws}+\frac{V_w \gamma_l}{F}\Delta p_p$ $\Delta p_{ws} = \gamma_b H_{stat}(1-\varepsilon_o)$	$\varepsilon_o = 0.4$; flow resistances of the sprayed grid Δp_p recommended by the authors to be calculated as below	[4]
Flow resistances through sprayed grid (with no packing) Δp_p, kg/m²	$\Delta p_p = (2\xi_p+1)\frac{\gamma_g}{2g}\frac{w_{go}^2}{(1-\tau)^3}+\frac{2\sigma}{a}$	$\tau = \frac{\sqrt[3]{g^2\frac{\varrho_g}{\varrho_l}\frac{1}{\beta^2\xi_p}}}{1+\sqrt[3]{g^2\frac{\varrho_g}{\varrho_l}\frac{1}{\beta^2\xi_p}}}$ accuracy of the formula ±20 to 25%	[15]
Total flow resistances Δp, kg/m²	$\Delta p = \Delta p_p+(1+0.01085\,L)\,H_{stat}\gamma_b$	accuracy of formula is ±20% at $\gamma_b < 500$ kg/m³	[11]
Total flow resistances Δp, N/m²	$\Delta p = \Delta p_o\left\{1+C\left[\left(\frac{G_l}{G_g}\right)^2\frac{\varrho_g}{\varrho_l}\right]^{k+1}\right\}$ $\Delta p_o = \frac{\xi_p \varrho_g w^2}{2\delta^2}+\varrho_b g H_{stat}(1-\varepsilon_o)$	$\varepsilon_o = 0.385\left(\frac{d^*}{d_b}\right)^{-0.07}$; m³/m³ constants C and k are calculated after Table 2	[7]

The Range of Studies Made by Various

Reference	Apparatus dimensions			No. stages	Retaining grid	
	diameter D m	height H_A m	grid spacing H m		cross section of free area $\delta \cdot 100\%$	slot width b mm
[3]	0.165		1.2	1	34.5	2
[4]	0.060 0.095 0.135 0.165 0.370			1; 3	25–70	2–6
[6]	0.2; 0.35	1.8; 2.8	0.4–1.2	1–3	19; 30 41; 90	14; 24; 25
[7]	0.175		0.6–1.2	1–3	30–60	2.1–5
[8]	0.305	0.61		1		
[10]	0.12		0.34	1	39.3–61	
[11]	0.15			1	30–65	
[12]	0.1		0.583; 0.829	2	46	
[13]	0.12; 0.3		0.5; 0.65		21	
[14]	0.175	1.2	0.6–1.2	1–3	30–60	2.1–5
[16]	0.68; 0.400 0.900				30–70	
[17],[18]	0.178		1.2		28.8; 36.4 40; 50	

Heldup of the gas φ is a measure of the interface area. Likewise the empirical formulas determining φ differ from one another, according to authors [3], [4], [7], and [14]. Good results are obtained using formula derived in [4]

$$\varphi = 0.93\left(\frac{\mathrm{Re}_b^2}{\mathrm{Ar}_b}\right)^{0.2} \tag{4}$$

under conditions $H_{stat} < 10\ d_b$ and for a low density of the packing ϱ_b, where

$$\mathrm{Re}_b = \frac{w_{ac} d_b \varrho_g}{\eta_g} \qquad \mathrm{Ar}_b = \frac{d_b^3(\gamma_b - \gamma_g)\gamma_g}{\mu_g^2 g}$$

Actual gas velocity in the packing

$$w_{ac} = \frac{w}{1 - \frac{V_{hl}}{H_D F}} \tag{5}$$

An essential problem is the calculation of the resistance to gas flow

Table 4

Authors Referred to in the Article

Static depth of packing H_{stat} mm	Packing characteristics			Gas velocity m/sec	Spray rate L m^3/m^2 hr
	ball diameter d_b mm	density	material		
0.045–0.175	3–36	250; 500	polyethylene	1–4.5	1–80
0.090; 0.170 0.260	6–35.5	160–910		1–6	
0.150; 0.700	38	180; 90	polyethylene	0.4–10	9–16.5
0.038–0.300	6–22	356–1056		0.1–8	0–125,000 kg/m^2hr
0.305	12.5 25.4; 38	156–170	polyethylene	3370–7850	9030–52,080 kg/m^2hr
0.018–0.1	8–12	800–900	polyethylene	2.26–4.5	10–108
	16	300		1–7.5	4.85–150
0.160	16	276–283	polyethylene		
0.05–0.20	17; 20 38	85; 162 275; 800			
0.038–0.300	6–22	356–1056		0.1–8	0–125,000 kg/m^2hr
				2.9–5.5	14,700–55,000 kg/m^2hr
0.070; 0.140 0.210	rings 30×30×30 half-rings 18×9×2 8×4×0.3	900 1083		1–4	0–61.5

in the scrubbers of the type under discussion. The problem was dealt with by numerous students [3], [4], [6]–[8], [10], [11], [15], [17], [18]. The changes in pressure loss of various nature were observed for different operating ranges of the apparatus, that is, for individual fluidization stages. A plot of the pressure loss vs. gas velocity, obtained by the authors of the paper [14], is shown in Fig. 3. The methods of calculation of the resistance to gas flow are to be found in the references cited above. The most useful formulas from a practical viewpoint are collected in Table 3 here.

The majority of investigators agree that the most economic conditions, as concerns pressure loss, are accomplished for the following parameters: density of the balls $\varrho = 600$ kg/m³, the ratio of static depth of packing to the scrubber diameter $H_{stat}/D \leqslant 1$.

The collection and absorption process in the spray fluidized-bed scrubber is highly complex. Solid particulates pass from gas to liquid largely via impaction of the particles on the wet surface of the balls and liquid streams and drops, which is the inertial mechanism, as well as by means of diffusion. Other mechanisms of importance in the dust collection process are adhesion, cohesion, and solubilization of dust. It was established [5] that collection efficiency is improved for a small spacing of the grids and for the top grid of suitable shape (Fig. 4). Owing to this a better circulation, tumbling, and higher frequency of their mutual collisions are achieved with the resultant improvement in the self-cleaning of the bed.

Collection efficiency of the scrubbers of the type discussed was examined by authors of papers [19] and [20]. In reference [19] results of studies on the treatment of exhaust gases from aluminum cells are provided. Chemical composition of the dust was the following: 0.37% SiO_2, 1.76% Fe_2O_3, 22.9% Al, 9% Na, 15.5% F, 0.67% CaO, 19.5% C; its particle size distribution was, in wt. %: 8% fraction < 2 μm, 22% fraction from 2 to 20 μm, 70% fraction > 20 μm. The studies were made in a semicommercial two-stage apparatus of a diameter $D = 420$ mm. Hollow polyethylene balls were 35 mm in diameter, and a specific gravity of 1860 N/m^3. The retaining grids were spaced 1.5 m apart; free surface area of the grids $\delta = 0.406$ m^2/m^2 and openings diameter $b = 6.1$ mm. The spray liquor was an aqueous solution of Na_2CO_3 containing 40 to 50 g/l. The characteristic operating parameters were varied in the following range: $w = 2$ to 6 m/sec, $H_{stat} = 35$ to 175 mm; $L = 7$ to 30 m^3/m^2hr; $\Delta p = 440$ to 1200 N/m^2. The transfer unit number, No, was shown to increase with gas velocity. Maximum No value was attained at $w = 5.6$ to 6 m/sec and $H_{stat} = 105$ mm.

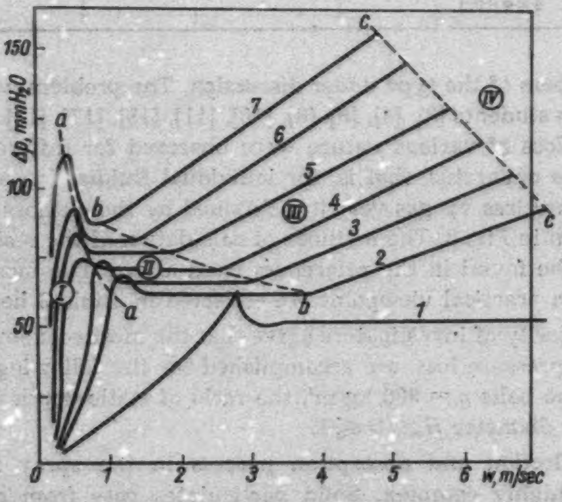


Fig. 3. Pressure loss across fluidized bed vs. gas flow rate: *I* — mobile bed (below *a–a* line); *II* — initial fluidization stage (*a–a* to *b–b*); *III* — full fluidization stage (*b–b* to *c–c*); *IV* — flooding condition (above *c–c* line); lines from 1 to 7 refer to various flow rates of the liquor.

Collection efficiency was then $\eta = 92$ to 95%. The transfer unit number No is expressed by formula

$$\mathrm{No} = \ln \frac{1}{1-\eta} = \ln \frac{C_{in}}{C_{out}} \qquad (6)$$

where

η — collection efficiency,

C_{in}, C_{out} — dust concentration at the inlet and outlet, respectively, mg/m³.

From the experimental data the following final formula was obtained for collection efficiency

$$\eta = 1 - \exp(-0.013\, K_T^{0.77}) \qquad (7)$$

where

K_T — horsepower used up for the treatment of 1000 m³ of gas, defined by relation

$$K_T = 1000 \left(\Delta p + p \frac{\dot{V}_l}{\dot{V}_g} \right);\ \mathrm{N/m^2} \qquad (8)$$

where

Δp — flow resistance in the apparatus, N/m² (Table 3),

p — spray liquid pressure, N/m².

Authors of paper [20] investigated collection efficiency of the scrubbers under laboratory conditions for the air/water system. Calculations of the collection efficiency were proposed for transient and full fluidization ranges, analogically to collection in foam scrubbers

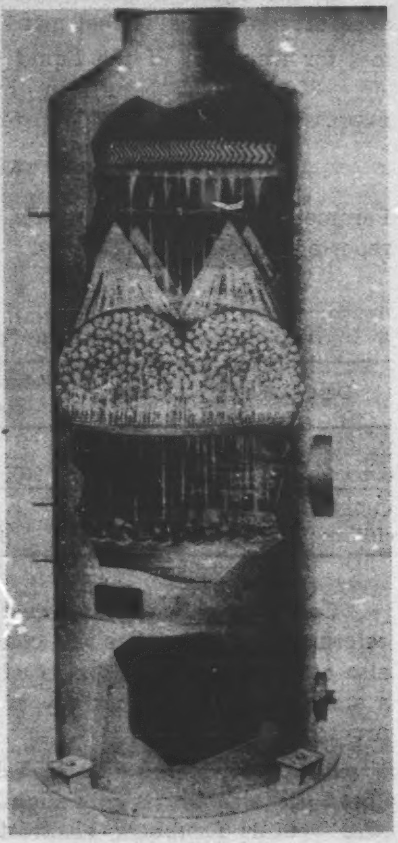


Fig. 4. A spray fluidized-bed scrubber with a parabolic top grid.

$$\eta = \eta_0 \left(\frac{H_D}{0.09} \right)^{0.075} \qquad (9)$$

where

η_0 — collection efficiency calculated on the basis of fractional curves of collection stages, for the foam scrubbers,

H_D — dynamic depth of packing, formula (3).

The experimental data showed a discrepancy for the formula not exceeding 1%.

A formula was also derived for the calculation of transfer unit number

$$\mathrm{No} = AK_T^{\varkappa} \qquad (10)$$

In the equation for K_T after formula (8) the pressure loss in the apparatus is the value that many times exceeds the value of horsepower loss for transport of the liquid ($p_{\min}$, $\dot{V}_l/\dot{V}_g = 0.0005$ to 0.001 m³/m³ at $\Delta p = 800$ to 2000 N/m²). In this connection the collection efficiency expressed in terms of the transfer unit number may assume the form

$$\mathrm{No} = A_1 \Delta p^{\varkappa_1} \qquad (11$$

Parameters A and $\varkappa$, or A_1 and $\varkappa_1$ for a vast variety of industrial dusts are reported in reference [21].

Table 5

Efficiency of the Spray Fluidized-Bed Scrubber

Dust kind	Standard			Polydisperse, coarse	Polydisperse, fine	Polydisperse, very fine
Particle dimension, μm	50	5	1	90% 60–10	70% < 10	90% < 10 and 50% > 2.5
Collection efficiency, %	99	99	60	99	96.2	82.7

Collection efficiency for dust of various particle size can be found in reference [22]. The data are collected in Table 5. In the same study is also covered a comparison of efficiency and costs of wet collection of a standard dust in a variety of typical equipment. The comparison is provided in Table 6.

Inspection of the data in Tables 5 and 6 shows that the spray fluidized-bed scrubber is only slightly inferior in performance to high-pressure Venturi scrubbers, electrostatic precipitators, and fabric filters. It is, on the other hand, much better than high-efficiency wet collection devices as regards collection costs per unit volume of the gas treated.

It follows from analysis of the formulas deduced in papers [3]–[20] for the determination of individual hydrodynamic quantities of the spray fluidized-bed scrubbers that the countercurrent three-phase fluidization process has thus far been little learned. Various investigators relate the same hydrodynamic quantities to different factors. Likewise the numerical constants and exponents in the formulas differ, which in consequence gives rise to unlike results. The studies were conducted for various systems and for diverse dimensions and operating ranges of the apparatuses, which makes generalization of the formulas unfeasible. Similarly, the majority of formulas obeyed under laboratory conditions fail in industrial practice. For that reason, in view of the notable advantages of the spray fluidized-bed scrubbers, detailed study should be made on the hydrodynamics and collection efficiency in at least a one-fourth scale.

Notation

a — unit area of packing, m^2/m^3

b — width of the slot of the retaining grid, mm

C — dust concentration in gas, mg/m^3

D — apparatus diameter, m

d_b — ball diameter, m

d^* — assumed standard ball diameter equal to 0.005 m

d_o — grid openings diameter, m

e — relative entrainment of the liquid, %

F — cross-sectional area of the apparatus, m^2

g — acceleration of gravity, m/sec^2

G — mass flow rate, kg/m^2hr

G^* — assumed standard mass flow rate of liquid $1 \cdot 10^5$ kg/m^2hr

h_{hl} — head of the liquid held up in the apparatus, m

H — grid spacing, m

H_D — dynamic depth of packing, m

H_{stat} — static depth of packing, m

H^*_s — assumed standard static depth of packing equal to 0.1 m

L — volume spray rate, m^3/m^2hr

m_{hl} — weight of the liquid held up in the apparatus per 1 m^2 of the area, kg/m^2

p — spray liquid pressure, N/m^2

Δp — total pressure loss in the apparatus, kg/m^2, N/m^2, mm H_2O

Δp_o — flow resistance of the dry apparatus, N/m^2

Δp_{sparg} — resistance due to gas sparging through the layer of the held up liquid, mm H_2O

Δp_{lp} — flow resistance through the liquid held up on the grid, kg/m^2

Δp_{lw} — resistance to flow through the liquid held up in the packing, kg/m^2

Efficiency and Dust Collection Costs of 60,000 ft^3/min = 1698 m^3/min of Dust-Laden

Device type	Efficiency (standard dust)	Prime costs		Device capacity per 1698 m^3 gas/min	Average pressure loss	Power consumption costs
		total	per $1 m^3$/min gas			
	%	£	£	m^3	mm H_2O	£/year
Jet impingement scrubber	87.9	30,000	17.70	312	8.0	3750
Wet cyclone	91.0	18,800	11.10	255	3.9	2030
Self-induced spray scrubber	93.6	21,000	12.40	255	6.1	2820
Spray tower	94.5	44,000	26.00	425	1.4	2380
Spray fluidized-bed scrubber	95.0	16,700	9.85	264	2.4	1550
Wet impingement scrubber	97.9	26,000	15.30	170	6.1	2900
Dynamic impeller-type scrubber	98.5	43,000	25.40	119	—	22,700
Wet electrostatic pricipitator	99.0	95,000	56.00	1020	0.6	1110
Low-energy annular-throat scrubber	99.5	32,000	18.85	566	12.5	5870
Venturi scrubber	99.7	34,000	20.00	566	20.0	9410
Annular-throat scrubber	99.8	34,000	20.00	566	20.5	9670
High-energy Venturi scrubber	99.9	37,000	21.80	566	31.5	14,870

Δp_p — flow resistance through the spray grid, kg/m^2

Δp_{ps} — flow resistance through dry grid, kg/m^2

Δp_{ws} — flow resistance through dry packing, kg/m^2

Δp_σ — resistance due to surface tension, kg/m^2

$\dot{V}$ — volume flow rate, m^3/sec

V_{hl} — volume of the liquid held up in the apparatus, m^3/sec

V_v — liquid holdup in 1 m^3 apparatus, m^3/m^3

V_w — liquid holdup in the mobile bed, m^3

w — gas velocity in the apparatus, m/sec

w_{min} — minimum fluidization rate, m/sec

w^*_{min} — minimum (gas) velocity of the entrainment of the wetted mobile bed on the assumption $Re_l = 0$, m/sec

w_{crit} — critical velocity at which full fluidization stage is attained, m/sec

w'_{crit} — velocity of the transition from the initial to intermediate stage, m/sec

w_{go} — gas velocity related to the area of the grid openings, m/sec

w^0_{crit} — critical velocity of fluidization of dry packing, m/sec

Table 6

Gas of a Temperature of 20°C in Wet Collection Devices of Various Types

Water consumption	Water consumption costs	Maintenance costs, etc.	Total costs of operation	Total capital costs annually	Total costs inclusive of capital costs	
m^3/m^3 gas	£/year	£/year	£/year	£/year	£/year	£/100 m^3 gas
0.103	140	320	4210	3000	7200	0.0088
0.516	660	160	2850	1880	4730	0.0057
0.077	110	210	3140	2100	5240	0.0064
2.320	3300	320	6000	4400	10,400	0.0127
1.875	2550	500	4600	1670	6270	0.0076
0.388	550	320	3770	2600	6370	0.0077
0.645	850	210	23,760	4300	28,060	0.0343
0.323	450	420	1980	9500	11,480	0.0140
0.905	1210	320	7400	3200	10,600	0.0129
0.905	1210	320	10,940	3400	14,340	0.0175
0.905	1210	320	11,200	3400	14,600	0.0179
0.905	1210	320	16,400	3700	20,100	0.0246

w_g — maximum permissible gas velocity in the apparatus, m/sec
w_f — flooding rate, m/sec
Re — Reynolds number
β — liquid flow rate coefficient in discharge
γ — specific gravity, kg/m^3
δ — part of the free surface area of the retaining grid, m^2/m^2
ε_o — porosity of dry packing, m^3/m^3
η — dynamic viscosity, kg/m sec
μ — dynamic viscosity, kgs/m^2
τ — the fraction of the free cross section of the grid occupied by the dripping liquid,
ϱ — density, kg/m^3
ξ_{lp} — coefficient of local resistances dependent on the grid characteristics,
ξ_{lw} — coefficient of local resistances dependent on the grid and packing characteristics,
ξ_p — coefficient of local resistances of dry retaining grid,
σ — surface tension at the gas-liquid interface, kg/m.

Subscripts

g — refers to gas,
l — refers to liquid,
b — refers to balls,
p — refers to retaining grid,
w — refers to packing.

REFERENCES

[1] Chemical Engineering — December 14, 106, 1959.
[2] Durych, A., Nowa Technika. Krystalizacja i Fluidyzacja — Issue 102, 203, 1973.
[3] Gel, N. I., Grishko, V. Z., Savchenko, V. I., Shchedro, V. M., Khim. Neftyannoe Mashinostroenie, No. 1, 22, 1966.
[4] Gel, N. I., Savchenko, V. I., Grishko, V. Z., Teoreticheskie Osnovy Khimicheskoi Tekhnologii, 2, 1, 76, 1968.
[5] Douglas, H. R., Snider, I. W., Tomlinson, G. H., Chem. Engineering Progr., 59, 12, 85, 1963.
[6] Blyakher, N. G., Zhivaikin, L. I., Yurovskaya, N. A., Khim. i Neftyannoe Mashinostroenie, No. 2, 18, 1967.
[7] Balabenko, O. S., Tarat, E. I., Romankov, P. G., Mikhalev, M. F., Zh. Prikl. Khim., 44, 5, 1061, 1971.
[8] Chen, M. H., Douglas, W. I. M., Canad. J. Chem. Engng., 46, 4, 245, 1969.
[9] Młodziński, B., Warych, J., Nowa Technika. Krystalizacja i Fluidyzacja — Issue 102, 229, 1973.
[10] Mayak, V. I., Matrozov. V. I., Teor. Osnovy Khim. Tekh., 3, 1, 79, 1969.
[11] Aksel, L. S., Yakovenko, M. M., Teor. Osnovy Khim. Tekh., 3, 1, 148, 1969.
[12] Kuznetsov, D. A., Koval. Zh. A., Bespalov, A. V., Kuleshov, O. G., Trudy Moskovskogo Khimikotekhnologicheskogo Instituta im. Mendeleeva, Issue 60, 144, 1969.
[13] Ivanyukov, D. V., Kupryanov, V. N. et al., Trudy Tambovskogo Instituta Khimicheskogo Mashinostroeniya, Issue 2, 275, 1968.
[14] Balabekov, O. S., Romankov, P. G. et al., Zh. Prikl. Khim., 42, 7, 1540, 1969.
[15] Malokonov, I. K., Khim. Prom., 4, 291, 1962.
[16] Valdberg, A. I., Gelperin, N. I., Tarasov, V. M., Khim. i Neftyannoe Mashinostroenie, 4, 12, 1972.
[17] Levsh, I. P. et al., Uzb. Khim. Zh., 5, 72; 6, 70, 1967.
[18] Levsh, I. P. et al., Izv. Vysshikh Ucheb. Zaved., Khim. i Khim. Tekhnol., 1, 115, 1968.
[19] Valdberg., A. I., Gelperin, N. N., Tarasov, V. M., Khim. i Neftyannoe Mashinostroenie, 2, 10, 1972.
[20] Valdberg, A. I., Gelperin, N. N., Zaitsev, M. M. et al., Khim. i Neftyannoe Mashinostroenie, 8, 14, 1973.
[21] Uzhov, V. N., Valdberg, A. I., "Ochistka gazov mokrymi filtrami." (Gas Cleaning with Wet Filters). Khimiya, Leningrad 1972, p. 248.
[22] Stairmand, C. J., Chemical Engineering, No. 194, T.I.CH.E., 43, 10, 310, 1965.

INDUSTRIAL BRIEFS

Operation of the Emission Control Equipment

The majority of industrial plants, within their activity related to the environment pollution control, are obliged to perform measurements of operation efficiency of the emission control equipment, and also to take measurements of the emission of dust, SO_2, and of other toxic pollutants released into the atmosphere. These measurements are usually made twice a year. Frequent measurements of the above kind help pinpointing incorrect operation of the equipment or else improper maintenance or the ways they are run. With some experience the quality of operation of this equipment can be judged from periodical inspection.

The emission control equipment, from the viewpoint of its application, may be arbitrarily classed into the following three groups:

— production line equipment,
— thermal process equipment,
— ventilation and air conditioning equipment.

Because the dust precipitated in the production line equipment type constitutes a by-product or feedstock for other processes, the emission control equipment of this group is carefully operated and maintained, and can be claimed, in principle, to meet the requirements expected.

Among the technical plants provided with the emission control devices that are designed to treat off gases from thermal processes rank: steam boilers, furnace for the production of building materials, and metallurgical furnaces.

The last group includes usually dust conveying and storing devices, feedstock preparation and processing, charge preparation and processing, and process machines. The gases released from the second-group plants (exhaust gases or air) are discharged into the atmosphere and represent a substantial share of the total particulate and gaseous emission rate. Hence, the adequate measures to ensure proper operation of this equipment is of prime import for the environment protection.

As opposed to the production line equipment, the dust collected is apparently of no commercial value, and the pollution control measures, from the process economy standpoint, is the necessary evil.

Considering the last two equipment groups it should be noted that the former is featured typically by a large volume of gaseous effluents, hence their nuisance to the environment is more serious than for the ventilation-type equipment.

Moreover, particulate emission from ventilation equipment is, as a rule, much lower, as the plant controlled often operates a mere few hours a day. This is particularly true of such machines (e.g., in foundries) as fettling plants, or molding sand conveying and preparation machines. The purpose of the emission control system here is double; for they are to improve working conditions in the production rooms as well as to control pollution of the atmosphere. Correct operation of the ventilation should be of particular concern for the safety at work and hygiene services of the production plants as well as for the plant crew, since faulty operation of the ventilation and emission control system entails a substantial deterioration of working conditions at workplaces.

It happens, however, that workers switch off an efficient emission control device or shut off the exhaust systems. The reason for that is excessive noise from fans whose noisy operation results either from their design or from extended overhaul or maintenance periods. Too deep erosion of the rotating parts causes unbalance and increased loudness of fans. In similar circumstances the crew that operates process equipment must make up their mind in choosing between the hazard of high dust concentration and noise.

In all the emission control systems considered the following four commonly encountered equipment groups may be distinguished:

— cyclone collectors,
— wet mechanical devices,
— filter collectors,
— electrostatic precipitators.

Every device of the individual group mentioned features some major parameters that critically affect its operation.

As regards cyclone collectors these parameters are:

— pressure loss,
— tightness, especially that of the closure of the conical section,
— inlet velocity.

For wet mechanical emission control devices the factors controlling their efficiency are feed rate or level of the scrubbing liquid (water), or characteristic velocity (e.g., velocity in the Venturi throat, or impingement velocity in the impingement scrubber).

Both groups of mechanical collector types usually lack in a suitable apparatus that would facilitate appraisal of operation or would enable their adjustment. In the filter collectors-type group the major parameters comprise filtering rate and regeneration of the filter material. These devices are often equipped with an extensive automation of the regeneration of filter medium and of an automatic control, e.g., of gas temperature.

A proper selection of regeneration parameters is often highly important for the operation or service life of the filter material as well as for dust concentration in clean gas. In the electrostatic precipitation systems the major parameters are: residence time of dust particles in the electric field, supply parameters, and the electrode cleaning parameters, e.g., time span between successive cleanups of the electrodes, and the time of the cleaning operation.

For the determination of the major parameters common to all the collector groups the following quantities are measured:

— gas temperature,
— static and dynamic pressures,
— chemical composition of gas,
— moisture content,
— dust concentration.

From the above data are determined: gas flow rate, collection efficiency of the device, its hydraulic resistance, exhausted gas volume, and dust emission rate. Moreover, for every collector type its characteristic operation parameters are found.

Based on the measurements and observations made it can be stated that in the majority of high-capacity emission control equipment, particularly in the treatment of flue gases, excessive leaks on the reduced-pressure side are not observed. This fact is understandable, as excessive leaks result in decreased amount of off gases released from a specific manufacturing process which brings about some disturbances in that process. Thus, to improve this condition, the manufacturer is compelled to correct immediately all the faults and irregularities.

The value of flow rate, hence the capacity of emission control equipment, is so much related to the volume of parasitic gases due to leaks in the exhaust system, that the leaks usually occur in all the doors, hatches and peepholes, whose size in principle is independent of the equipment capacity. In this connection the leaks that develop on a high-capacity plant represent a small percentage of the cross section of the dirty gas feeding ducts. Evaluation of the resistances to gas flow and leaks becomes of prime significance for installations treating dust-laden gas exhausted from over workplaces of dust-generating process equipment. Excessive rise in flow resistance appreciably lowers the volume of exhausted air with the resultant apparent deterioration of working conditions.

It happens frequently that dust collectors are overloaded with precipitated dust due to faulty operation of the dust disposal system. Also not infrequently the high flow resistance results from dust deposits accumulated in ducts and pipelines, especially if the collector is operated periodically or if it serves a large number of local exhaust ducts.

Another factor that reduces the quantity of exhausted air are leaks which frequently achieve over a few scores or even above 100%. For illustration one can consider a plant designed to control air exhausted in a quantity of 100 m^3/min. The leaks are evaluated from formula

$$\Delta V = \frac{V_2 - V_1}{V_1} 100\%$$

where

V_1 — the amount of gas upstream of the collector,

V_2 — the amount of gas downstream of the collector.

Assuming that fan operates with the designed capacity, and the leaks equal 100%, the quantity of exhausted air takes the value

$$V_1 = \frac{V_2 \cdot 100}{\Delta V + 100} = \frac{100 \cdot 500}{100 + 100} = 50 \text{ m}^3\text{/min}$$

As can be seen, 100% of leaks means that only half of the dust-laden air is exhausted; the remainder spreads unorderly around the workplaces.

An additional evil here is if the crew operating the emission control equipment puts out the control systems, since the plant working with high resistances and leaks may show all the signs of a correct operation. Then the localization of leaks is quite essential. All the wornout spots on the feeding ducts and pipelines, housing, or hatches substantially decrease the volume of exhausted air from over the dust-generation places.

A frequent case is the leakage at the spots the dust is disposed of from under the collector. The leaks occurring there not only result in enhanced parasitic air but they also give rise to reentrainment of dust. An example may be cyclone banks or else single cyclone collectors, especially when the closures on the dust disposal system are made in the form of swivel flaps. Not infrequently the flaps do not close tight and the reduced pressures occurring there attain a few scores of mm H_2O.

It happens therefore that even though dust is separated from gas carrier in the collector, emission is as high as if the collector would not be operated at all, since the precipitated dust is reentrained and ejected into the atmosphere.

From the above remarks and examples it follows that for emission control systems the flow resistances as well as leaks should be permanently controlled. The flow resistance could be easily controlled with the most simple pressure gauge like a U tube. The leaks, on the other hand, can be localized by inspection of pipelines, ducts, joints, hatches, flaps and the elements through which dust is disposed of.

In turning now to the deficiencies and erroneous operation we will dwell upon wet collectors or, more exactly, induced liquid-contact inertial collectors or impingement scrubbers, etc.

The essential requirement for operation of the equipment of that kind is the provision of a suitable water level. Unfortunately these collectors are operated without requisite water level on account of lack or faulty operation of water level control systems. As a result, the devices that are capable of attaining 95% collection efficiency run with a highly reduced efficiency. This condition is also due to poor performance of the sludge disposal system.

Devices with damaged sludge disposal system or with faulty sludge worm conveyor are all too often encountered. Because of this the emission control device is filled up with sludge and cannot perform well.

As far as the filter collectors are concerned the remarks made previously as to increased flow resistance, excessive leaks, or accumulation of dust deposits in the ducts are likewise valid here. Some extra problems are damaged regeneration systems or regeneration run at incorrectly chosen frequency and sequence. A frequent place where leaks occur are unclosing flaps on the air reversal supply. Without systematic maintenance and inspection filterbags not infrequently break or wear out in spots.

To verify whether or not the emission control installation meets, or can meet, the requirements, attention should be paid to these elements that seemingly have no direct relation to the dust collection process itself. These elements are transport and dumping of the dust. This is particularly true of dry electrostatic precipitators. The problems in the removal of dust from hoppers should be sought in fairly frequent damages to the dust conveyance system or even in insufficient number of the crew serving the dust disposal device.

Occasionally there occur difficulties in the building of a successive dumping ground, which makes the manufacturing plant "save" the space available in the old ground. This saving consists in temporary switching off the high-voltage supply from the precipitators. This is an instance in support of the point that an adequate technical condition of the precipitator itself is not enough, but the whole installation must be taken care of.

Talking about some shortcomings in maintenance and operation, or even about poor operation, it should be borne in mind that there are many more problems of that kind in addition to those treated above and considered merely as typical illustration often encountered with in manufacturing plants.

It will be emphasized that the problem of correct operation is of great social impact, as it concerns a fairly high number of pieces of emission control equipment provided in industrial plants. The widespread occurrence of the phenomena of that kind suggests that it is much easier to order taking measurements than to overhaul and properly operate and maintain the emission control equipment. Even if it is taken into account that part of the equipment is being attended to and rennovated before the measurements (cleaning and routine repair), and that during the measurements some defects, faults and impairments are detected, the advantages are, however, too small compared with the expenditure of labor and money related to the measurement taking.

If one would like to find the reasons for this state of affairs, one should pay attention to the insufficient crew for overhaul of emission control equipment. This equipment, unless it makes the process plants be turned off, is as a rule overhauled and repaired in the second turn. Even in major manufacturing plants the services specifically concerned with maintenance of emission control equipment are unavailable. It is often much easier to invest millions of zlotys in the construction of high-efficiency emission control units than to ensure their correct operation and maintenance by trained personnel. This results in a fast wearout of not infrequently expensive installations with accompanied rise in the volume of dusts and deteriorated working conditions at the dust-generating workplaces.

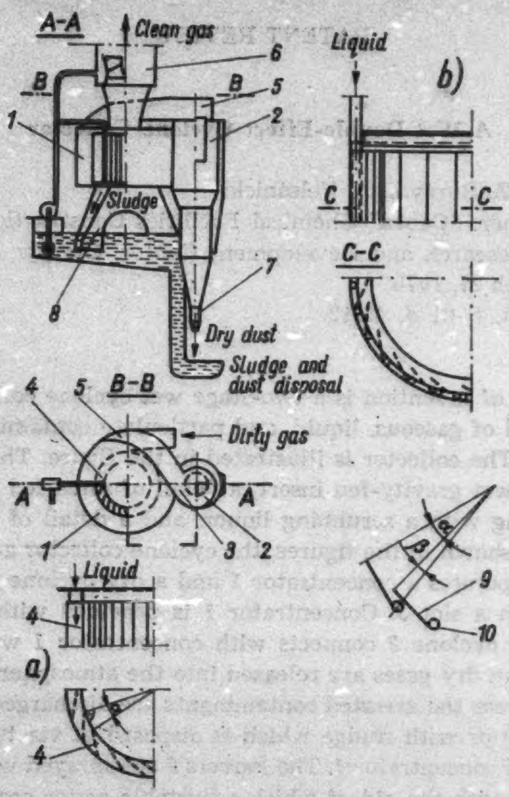
Prepared by Z. Kocjan

PATENT REVIEW

A Wet Double-Effect Cyclone Collector

Inventors: Z. Burzym, A. Teleśnicki
Patent owner: "Cebea" Chemical Facilities Construction
Industry Research and Development Center, Cracow
Filed: March 27, 1970
Cl. internat. B 01 d, 45/12
No.: 81330

The object of invention is a two-stage wet cyclone collector designed for the removal of gaseous, liquid, and particulate contaminants from industrial gases. The collector is illustrated in the figure. The figure shows a detail of the wet gravity-fed insert, a detail of force-fed filtering insert with the feeding with a scrubbing liquor, and a detail of the louver arrangement. As shown in the figures, the cyclone collector according to the invention incorporates a concentrator *1* and a dry cyclone *2* connected to each other with a slot *3*. Concentrator *1* is provided with a wet louver element *4*. Dry cyclone *2* connects with concentrator *1* with a backfeed duct *5*. The clean dry gases are released into the atmosphere through outlet duct *6*, whereas the arrested contaminants are discharged through hopper *7* (dry dust) or with sludge which is disposed of via tube *8* provided in the bottom of concentrator *1*. The louvers *9* are sprayed with liquid from spray pipes *10*, with the aid of which adjustable water spray screens are produced around louvers *9*, not shown in the figure. Louvers *9* may also be sprayed using a gravity-feed system. Spray pipes *10* can be rotated, and are mounted in the housing of the wet louver insert *4* with a suitable provision for their adjustment during cyclone operation. Louvers *9* are spaced on the perimeter of the wet louver insert *4* at an angle α preferably 15°, and the arrangement of spray pipes *10* at the ends of the louvers *9* is such that it makes individual louver flaps overlap. The angle of overlapping radii β is about 5°. The collector operates in such a manner that dirty gas is delivered by aspiration or overpressure to concentrator *1* provided with wet louver insert *4* from which a part of the volume of the gas supplied, upon being compressed by the dust thrown off by centrifugal force against the wall, is forced through slot *3* to dry cyclone *2*. The gases cleaned in dry cyclone *2*, having followed their rotary path, are backfed to concentrator *1* via backfeed duct *5* in such a way as to make them pass again through wet louver insert *4* moistened with liquid supplied by gravity or

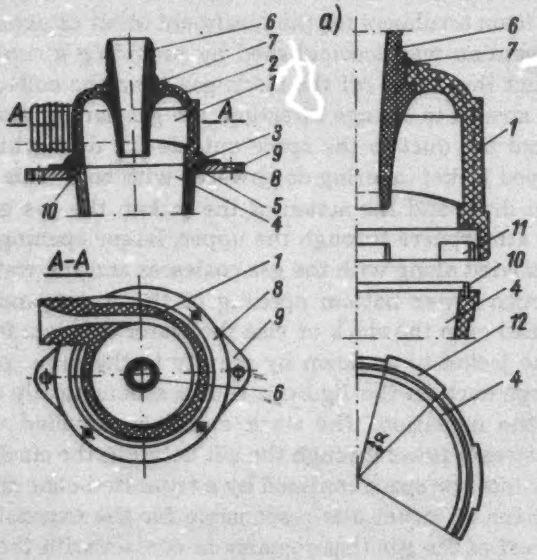


force system. The louvers elements spaced along the generatrices force such velocities of the flowing gases which cause liquid mist to be entrained. A secondary dispersion system is formed from the droplets entrained which remains suspended in the outlet tube *6* representing thereby a filtering baffle, not shown in the figure, on which distribution of inhomogeneous gaseous mixtures takes place both in the gas–solid (especially in the 1–5 μm range), gas–gas, and gas–liquid systems. The clean gases are vented to stack via outlet tube *6*. The dry dust precipitated is removed from cyclone *2* through hopper 7; the remaining contaminants trapped in the wet louver insert *4* as sludge are disposed of via tube. *8*. To separate gaseous contaminants from the gas treated scrubbing liquids should be used that are capable of combining with or neutralizing these contaminants.

A Hydrocyclone for the Separation of Solid in Liquid Suspension

Inventor: S. Bednarski
Patent owner: "Cebea" Chemical Facilities Construction
Industry Research and Development Center, Cracow
Filed: December 9, 1970
Cl. internat. B 04 c, 3/00
No.: 81216

The object of invention is a hydrocyclone for separation of suspension of solid in a liquid, particularly separation into a clear fraction and a concentrated thickened-up fraction. The hydrocyclone according to invention consists of head *1* provided with a tangential inlet tube, said head being closed from the top with a dome *2* and ending at the bottom with an annular lip *3*, a conical outflow section *4* with an annular lip on top *5* and an overflow nozzle *6*, said nozzle is joined to dome *2* of head *1* by means of lock ring 7. A clamping collar *8* is provided to hold down head *1* on conical outflow section *4*, collar *8* can be, for instance, bolted to support-

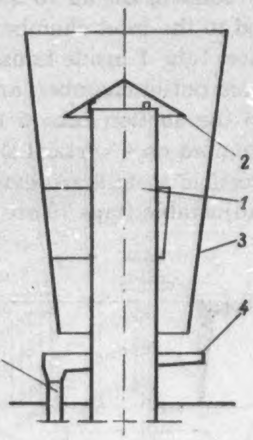


ing flange *9*, and to achieve tight joint axial arrangement of head *1* and section *4*, a sealing and guide ring *10* are provided in the grooves on the contact planes of head *1* and section *4*. Head *1* of a hydrocyclone variant has a number of cuts on its perimeter in its lower part, said cuts *11* engage with lips *12* provided on the perimeter of conical outflow section *4* on its top, and, upon twisting of conical outflow section by a suitable angle *α*, cuts *11* and lips *12* lock in position to make a coupling between head *1* and section *4*. A variety of conical outflow section of the hydrocyclone is shown in Fig. *a*.

A Mist Eliminator for Wet Collectors

Inventors: J. Mencner, J. Skorupa, H. Kazielski, J. Spandel
Patent owner: "Marcel" Coal Mine, Radlin
Filed: October 29, 1970
Cl. internat. B 01 d, 45/06
No.: 81148

The object of invention is a mist eliminator for wet collectors, and especially for foam scrubbers for the treatment of air or exhaust gases. The purpose of invention was accomplished by providing a conical hood over the venting duct that takes off the clean gas from the collector, said hood forces the gas stream to change direction, the gas carries along water mist and passes from the duct to the space outside the duct which is confined by a cone-shaped jacket tapering downwards with both ends open. As a result of natural draft and the action of the jacket, the gas goes up in that space into the atmosphere through the upper, larger opening of the jacket, and the mist carried along with the gas coalesces and the water drips down towards the open lower bottom opening of the jacket and directly into a gutter attached onto the stack or else the water droplets form on the inner wall of the jacket to go down by gravity to the same gutter provided with a discharge duct. In the figure is shown schematically an example of execution of the invention. The stack end *1* is provided with a conical hood *2*. A gas stream flows through the slit between the stack and the hood from the stack into the space confined by a truncated-cone shaped jacket *3*. The conical shape of jacket *3* is responsible for the expansion and subsequent cooling off of the gas that remains in contact with the inner wall of jacket *3*. At the same time, as a result of natural draft, the ambient air begins to flow through the open bottom end of jacket, said air mixes with the gas stream and cools the gas off even more. As a result, more moisture precipitates and the remaining water droplets together with micrograins of particulates precipitate largely on the inner wall of jacket 3, along which they drip and get into the discharge pipe 5. The steam produced as a consequence of gas expansion but not precipitated on the jacket 3 inner wall, thus steam of the finest droplet size, escapes into the atmosphere to vanish there. An additional advantage of the mist eliminator according

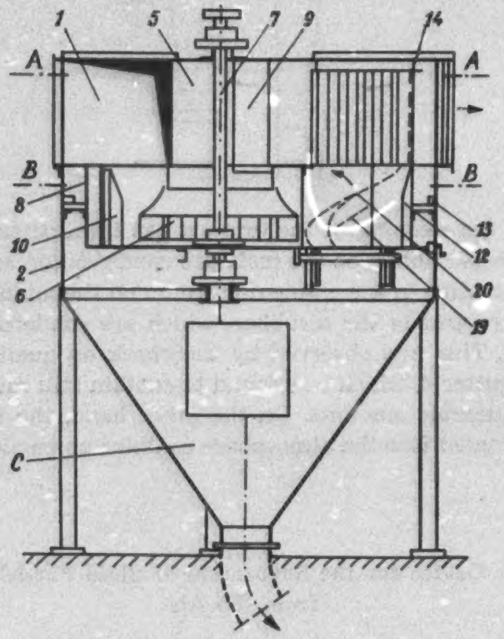


to invention is the cleaning of the exhaust gas from particulate emissions untrapped in the scrubber, as the moisture condensation as a result of gas expansion and cooling in the eliminator occurs on the minute solid particulate grains untrapped in the scrubber, which are condensation nuclei for water droplets. This was observed by the check on quality of the water discharged in gutter 4, which was found to contain still minute particulate grains in considerable amounts. On the other hand, the milky moist gas plume that is vented into the atmosphere contains no particulates.

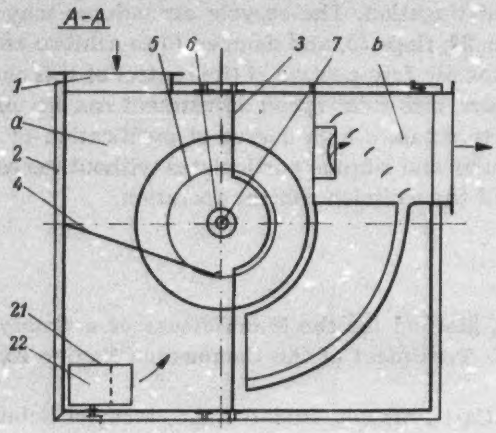
A Device for the Separation of Solid Particles from the Air

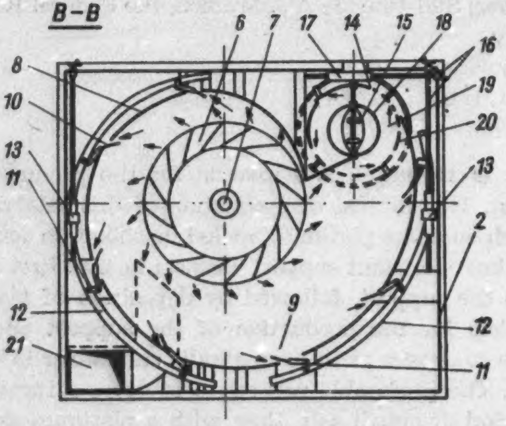
Inventors: G. Rumiński, J. Pietrzykowski
Patent owner: Poznań Plumbing Enterprise
Filed: January 27, 1973
Cl. internat. B 01 d, 45/14
No.: 84260 (provisional)

The object of invention is a device for mechanical separation of solid particles like granular or fibrous dusts, by centrifugation. The invention is featured by the use in the dust separation device of a conical rotor with top and bottom disks with blades bent backwards, said rotor being mounted in a spiral housing which is provided with slits and vanes that let some of the air along with dust pass into the dust hopper, and in the diffuser section of the spiral housing there is a two-jacket cylinder with a spiral guide vane that allows also some of the air to the dust hopper, and the dust hopper section is connected to the inlet chamber with a recycle duct. Inlet chamber equipped with inlet tube *1* inside housing *2* has a partition *3* that separates inlet chamber from outlet chamber, and is provided with a baffle *4* that directs the air into the suction tube *5* attached above the conical rotor *6*. Conical rotor *6* mounted on a vertical shaft *7* is housed in a spiral-shaped wall *8* in which vertical slots *9* are evenly spaced that accommodate adjustable flaps *10*. Adjustable flaps *10* are connected to pullrod joints



13 by means of levers *11* and common pullrods *12*. In the diffuser section of the spiral wall *8* the two-jacket vertical cylinder is placed, in the outer jacket *14* of which openings are provided that accommodate adjustable flaps *15* which are connected through pullrods *16* with pullrod joint *17* and external jacket *18*, which forms a cylindrical passway with a damper *19* that controls its opening. Mounted between jacket *14* and jacket *18* are spiral guide vanes *20* to allow part of the air to dust hopper section c. Dust hopper section *c* is additionally connected to inlet chamber *a* with a recycle dust *21* provided with damper *22*. Shortly before the device is started, exhaust fan is switched on, which is an independent unit outside the device. Thanks to the fan draft and the speed of air flow, rotor *6* is induced to rotate to achieve about 400 rpm. Subsequently, rotor *6* drive motor is





switched on. The dust-laden air goes through tube *1* entering chamber *2* then through suction tube *5* onto rotor *6*. Dust particles are inertially thrown against the spiral housing wall *8* via rotor blades and, through slots *9* with a suitably adjusted flaps *10* the particles with a part of air enter dust hopper chamber *c* where they fall into the hopper and to dust bin. Part of the dust, present in the air pushed on by the rotor *6* into the diffuser section, flows with the air in a helical path imparted by spiral guide vanes *20*, between jacket *14* and jacket *18* and, through the openings with adjustable flaps *15*, it is forced into the dust hopper section *c*. Clean air goes upward through cylindrical passway provided with a control damper *19* into outlet opening. The excess of air from the hopper section *c* is led off to inlet chamber *a* through duct *21* provided with damper *22*. The recycle air undergoes a recentrifugation. The recycle air volume may be adjusted by flaps *10*, damper *22*, flaps *15*, and damper *19* to achieve required degree of purification of the air. Irrespective of the control of this characteristic with flaps and dampers, also rotor speed adjustment can be used. This kind of control is good to obtain a high degree of purification of air from a wide variety of granular and fibrous particulates without necessity to resort to a second stage of the emission control operation.

A Method for the Manufacture of a Catalyst for the Treatment of the Combustion Engine Exhausts

Inventors: Carl Hofstadt, Rudolf Fahn, Michael Schneider,
Günter Donga
Patent owner: Süd-Chemie AG, Munich, the Federal Republic
of Germany
Filed: September 1, 1972
Cl. internat. B 01 d, 11/00
No.: 79501

The object of invention is a method for the production of a motor exhaust catalyst. The method of production of this catalyst, according to invention, which contains platinum, nickel or cobalt as active components deposited on a heat-resistant support consists in that first nickel or cobalt is deposited on the support, followed by deposition of platinum, and the starting materials for the production of the support and of the active components are so chosen as to have alkalis and sulfur in the catalyst below 0.05 wt.%. The preferable procedure involves saturation of the support with a nickel or cobalt salt, then with a platinum salt solution, and the support is dried and calcined following every saturating. The catalyst active components alternatively are precipitated on the support, and the support may be, for instance, in the form of suspension in the solution of active components salts. From this solution nickelous or cobaltous hydroxides are precipitated with alkalis, and by addition of a reducing agent or other reagent precipitants, the metals settle on the support surface, whereupon the support with the metallic components deposited is dried and calcined. As the starting materials commonly are taken water-soluble platinum, nickel, or cobalt salts, for instance, chloroplatinic acid, nickelous or cobaltous chloride, nitrate, or acetate. A preferable method for the production of the catalyst consists in that as starting material aluminum alkoxide is used, which is hydrolized with water, the aluminum hydroxide produced is dried, pelletized, and calcined prefarably at a temperature of at least 500°C to convert aluminum hydroxide to aluminum oxide Al_2O_3. The alumina pellets obtained are first saturated with aqueous solution of a nickel or cobalt salt, then with aqueous solution of a platinum salt, and the support is calcined at a temperature 350°C to 700°C following every saturation. The starting materials for the catalyst active components are so chosen as to make the resultant platinum content in the catalyst equal to 0.01 to 1 wt.% and from 0.1 to 10 wt.% of nickel or cobalt, and especially from 0.05 to 0.3 wt.% of platinum and from 1 to 5 wt.% of nickel or cobalt. The ratio of platinum to nickel or cobalt on the weight basis amounts to some 1 : 1000 to 10 : 1 relative to metals, and preferably from 1 : 100 to 1 : 3. If a mixture of nickel and cobalt is used as the active component, the weight ratio of these metals is preferably from 1 : 100 to 100 : 1, especially from 1 : 10 to 10 : 1. A good activity is achieved with the catalyst which contains only nickel as active component, beside platinum. The catalyst obtained by the method of invention contains preferably from 98.95 to 94,7 wt.% support and from 0,005 to 0,3 wt.% platinum and from 1 to 5 wt.% nickel.

Prepared by P.P.

NEWS IN BRIEF

The 16th Advanced Technology Workshop on Ventilation and Ventilation Equipment

Within the framework of a permanent activity of the Society of Polish Mechanical Engineers and Technicians which activates the engineering community, on October 5–6, 1976 the Katowice Branch of the Society launched an Advanced Technology Workshop of Technological Advance in Ventilation and Ventilation Equipment. Coparticipants of the event included:

— "Klima-Went" Union of Air-Conditioning, Ventilation and Dust Collection Equipment Industry, Katowice Branch,

— "Fawent" Fans Works at Chełm Śląski,

— Silesian Institute of Technology in Gliwice, Institute of Machine and Power Facilities.

During the workshop own accomplishments were presented in the field of designing and production technology of ventilation equipment along with the experience in operation by foreign companies, such as, among others:

— Solyvent-Ventec, France,

— Kühnle, Kopp, Kausch, the Federal Republic of Germany,

— Sirocco, Great Britain.

Industrial fans are used in a variety of branches of national economy such as: power facilities and machines industry, in the metallurgical or chemical industries, in coal mining and in mining of other minerals, in shipbuilding industry, housing and industrial building.

The purpose of the workshop, which is related to those fields important for national economy, was the following:

— demonstration of the state-of-the-art designs of fans and ventilation equipment,

— presentation of the development trends in the domain of fan in the world and in this country,

— demonstration of the sound principles of sound operation,

— pointing out the guidelines for the choice of fans and for the designing of ventilation systems,

— treatment of the principles of a correct operation and maintenance of ventilation equipment,

— exhibition of the information material provided by the manufacturers of this equipment (catalogs, leaflets, prospectuses, standards, technical specifications),

— exhibition of patents and industrial designs.

The main objective of the event, however, was a direct confrontation and exchange of experiences and views of the inventors (designers), manufecturers, and users of ventilation equipment in the aspect of the current needs, and production, the quality of that production and its possible intensification.

During the event a number of reports were delivered, of which the most interesting were:

— Power Industry Fans of the Domestic Make,
— Review of the Research Subjects in the Field of Fans,
— Industrial Vacuum Cleaners,
— Automatic Use of the Fan Performance Factor in Model Studies,
— Absorption Noise Suppressors in Power Industry Fans.

A total of 82 design projects were admitted to be shown during the workshop.

J.K.

The World's Standardization Day

October 14 is traditionally observed as the World's Standardization Day. It has been thirty years in 1976 since the first meeting of the International Standardization Organization (ISO) was held in London, with participation of merely a hundred representatives from twenty-five countries. Today over one hundred experts from eighty countries are engaged in work within ISO activities helping in the establishing of increasing number of international standards. Results of their efforts, universally available, embody huge amount of technical experience and know-how. International standardization plays a notable part in promoting world trade. It helps the trade development by unifying a vast number of regulations whose diversity offers some obstacles of technological nature at least as hampering as customs or other trade restrictions. The standardization activity conducted worldwide is an important factor for international cooperation contributing thereby to a détente. It is because of this role of standardization that a special article has been devoted to this activity in the final act of the Helsinki European Security and Cooperation Conference, in which all kinds of international standardization are recommended.

International standardization activity is conducted by a number of organizations. The major, most recognized agency is International Standardization Organization (ISO). Its members are national agencies entrusted with standardization. These agencies, which currently number 64, have the status of member committees within ISO. The countries in which there are no such organization, and standardization there stays with departments of other central authorities, are represented by these departments which enjoy the status of correspondent members. The correspondent members total 18. Thus ISO has 82 members of both types. ISO came into being in 1946 in place of the International Federation of National Standardization Societies created in 1926. The work is divided over Technical Committees which total now 170. Within the majority of committees there are subcommittees which often appoint working parties. To date there is a total of 1629 bodies within ISO. The top authority of ISO is General Assembly held every three years. Current work is entrusted to Main Secretariate with its headquarters in Geneva. This body is headed by ISO Secretary.

A lively standardization activity is being developed also within COMECON. The activity essentially runs along two lines. Firstly, individual permanent specialist committees elaborate COMECON standards. Secondly, there is Permanent Standardization Committee whose scope of activity includes coordination of standardization work and establishing of the standards. There is also COMECON Standardization Institute with headquarters in Moscow concerned with research in the field of standardization and development of methodical guidelines.

Poland is very active in all the COMECON standardization projects. Among others, jointly with the Soviet party, Polish party may be credited with the initiative to establish COMECON standards. Annually Polish party works out about 20% of draft specifications for COMECON standards. Particularly active are Poland's representatives in Permanent Committees for machine building industry, chemical industry and transportation. Polish party participates in 115 committees out of the total of over 160 ISO committees, heading the secretariate of one technical committee and of a few subcommittees and working parties. Within the framework of the ISO activities the Polish party works out annually about 30 subjects and issues about 600 expertises. In addition to the participation in international organizations related to standardization, the Polish Committee for Standardization and Measures has signed the bilateral cooperation agreements with all counterpart organizations in the COMECON member countries, as well as with standardization agencies in Great Britain, France, Italy, and Sweden. The cooperation involves, among other things, consulting, exchange of standardization materials, preparation of papers for journals, as well as a joint work on selected topics.

J.K.

REVIEW OF PAPERS

357. Szwed, H., Wróbel, A., Hanpt, A., "Kierunki modernizacji urządzeń odpylających." (Trends in Modernization of Emission Control Equipment) — Zeszyty Naukowe AGH, No. 561, 1976, Sozologia i Sozotechnika, Issue 9, p. 19–26 (7 figs.).

The ever-increasing requirements as concerns emission control efficiency impose the need of developing new designs aimed at increased filtration rate. Work performed in this field is discussed, which includes electrostatic precipitators, fabric filters, and wet collectors.

358. Kusiak, A., Klima, K., "Odpylanie sortowni spieku w aglomerowni Huty im. Lenina." (Emission Control of the Sinter Grading Plant of the "Lenin" Ironworks Agglomeration Department) — Zeszyty Naukowe AGH, No. 561, 1976, Sozologia i Sozotechnika, Issue 9, p. 27-33 (1 fig., 4 tables).

Studies made at one point of the grading plant with the use of various emission control devices are discussed. The most suitable was found cyclone collector designed by "Biprohut" Designing Office, Gliwice, B type ϕ 700 of a capacity of 4400 to 5200 m^3/hr. It was, at the same time, assumed that the best solution for the control of emissions from the grading plant will be a master emission control system which will control all the dust generating sites, to replace the existing eight systems. Tests made, along with observations and measurements, demonstrated a high efficiency of the cyclones and the soundness of the concept admitted.

359. Grabowski, W., "Odpylanie gazów z pieców szybowych w Hutach Miedzi Legnica i Głogów." (Shaft Furnace Exhaust Treatment in the Legnica and Głogów Copper Mines) — Rudy i Metale Nieżelazne, No. 7, 1976, p. 268–269 (5 figs.).

Operation of the emission control systems equipped in the Legnica and Głogów Mines is treated. Shortcomings and advantages of these systems are pointed out. The most suitable solutions are presented on the basis of the results obtained.

360. Kornalewski, T., Wojnar, E., Wróbel, J., "Badania przemysłowe analizatora spektrofotometrycznego do pomiaru stężenia SO_2." (Industrial Testing of the Spectrophotometric SO_2 Analyzer) — Zeszyty Naukowe AGH, No. 561, 1976, Sozologia i Sozotechnika, Issue, 9, p. 35–45 (9 figs., 2 tables).

The measuring principle of the SO_2 determination and the design and calibration of the Ultramos 24 analyzer are covered. Results of commercial testing of the analyzer confirm its usefulness for a direct determination of SO_2 concentration in flues under reduced pressure in the duct min. 1500 N/m^2. Permissible exhaust temperature up to 200°C. The measuring range of the analyzer from 0 to 1500 ppm.

361. Josztowa, E., Zagórska, J., Jackowska, J., Kusiak, A., Lachowicz, J., "Emisja tlenków azotu z paleniska kotła przy równoczesnym spalaniu węgla kamiennego i gazu wielkopiecowego." (Emission of Nitrogen Oxides from Boiler Furnace during Simultaneous Combustion of Coal and Blast-Furnace Gas) — Zeszyty Naukowe AGH, No 561, 1976, Sozologia i Sozotechnika, Issue 9, p. 61–70 (6 figs.).

Results of the measurements are reported, which were performed on a coal-fired or blast-furnace gas fired metallurgical boiler. The results are in a good agreement with a number of conclusions made earlier as to the effects controlling the emission from power boilers over a wide range of the heat shares of both fuels. The emission indices obtained for $NO+NO_2$ expressed as NO_2 vs. the percent share of the blast-furnace gas in the fuel ranged from ca. 0.4 kg NO_2/ton steam with gas percentage of 60%, to 0.8 kg NO_2/ton steam with the gas percentage of 20% of the heat share. Thus emission of oxides of nitrogen can be reduced from metallurgical boilers by 50% without serious changes in the boiler design.

362. Ozóg, T., Kowalski, A., "Odpylanie gazów zawierających wysoko dyspersyjne pyły ołowiowe w filtrze pulsacyjnym z włókniną Nomex." (Collection of High-Dispersion Lead Dusts Using a Nomex Fabric Pulse Filter) — Biuletyn Instytutu Metali Nieżelaznych, No. 3, 1976, p. 115–119 (3 figs., 4 tables).

The problem of collection of high-dispersion lead oxide dusts is discussed. Attempts were made to arrest such dusts in an experimental pulse filter. The studies were made at a filtration rate of 2 to 4 m/min and various regeneration frequencies. The filter was found adequate for the purpose assumed under conditions examined. Regeneration frequency vs. filtration resistance was determined, and no relation was found for the range of

the parameters studied between filtration rate and collection efficiency. The studies performed substantiated the notable advantages of the pulse filter, especially the suitability for work under high gas loads. If Nomex-fiber nonwoven cloth is used filtration can be run at temperatures up to 200°C, and thus the need to admit ambient air in large quantities to cool the gas can be obviated.

Prepared by J.M.

ANNOUNCEMENTS

A Competition for Improved Working Conditions

The Central Council for the Trade Unions, the Polish Federation of Engineering Associations (NOT), the Ministry of Labor, Wages, and Social Affairs, and the Ministry of Science, Higher Education and Technology invite entries for an open competition held every year for the following:

— the most technologically advanced and economically sound solutions for modifications in the manufacturing processes, machines and production equipment, featured by high qualities in terms of ergonomy and work safety, combined with a substantial progress their use would bring in this field;

— solutions and improvements aimed at a considerable betterment of unsatisfactory situation in the work safety aspect and at ensuring better conditions of safety, health and convenience of work, both at a workplace and in the whole plant.

The objective of the competition is:

— a permanent and universal improvement in working conditions when implementing new design equipment, perfectioning and improvement of the existing processes in individual manufacturing processes;

— a perceptible improvement in work safety and hygiene.

The subject matter of the competition includes solutions and projects in technology and organization of a novel character which would lead to an appreciable limitation or elimination of such effects as:

— toxic or otherwise harmful and posing public nuisance atmospheric emissions, and fire and explosion hazards,

— excessive noise and vibrations,

— excessive electromagnetic radiation,

— electric current shock and statics shock hazards,

— injury hazards and other hazards or nuisances which are the most common reasons for accidents at work and causes of occupational deseases.

The solutions developed and checked upon in practice are to be subjected until December 31, 1977 to the Plant Competition Boards or directly to the Qualifying Boards at the address of the Voivodship Branches of NOT.

The papers submitted for qualification should contain:

(a) general information such as:

— title of the work,

— authors' names,

— estimation of the share of the work of individual persons with a suggestion as to division of the prize, if awarded (the prize per one author cannot be lower than 10%);

(b) technical and economic specifications composed of the following:

— a brief description of the previous technical and organizational conditions and working conditions of the crew,

— a detailed description of the solution implemented with specification of the essentials and the character of the solution, the degree of reduction of the hazards achieved in practice, the degree of improvement of working conditions at individual workplaces in departments and plants, specifying the number of persons for which working conditions have improved, and also itemization of the workplaces, departments, and manufacturing plants, industries where this solution can be implemented and widely accepted.

The following prizes will be awarded for the winners:

1st prize up to 200,000 zlotys
2nd prize up to 100,000 zlotys
3rd prize up to 40,000 zlotys.

J.K.

MISCELLANEOUS

A Sweden-GDR Agreement

An agreement has been signed in Berlin on cooperation in the environment protection between Sweden and the German Democratic Republic. On behalf of Sweden the agreement was signed by Minister of Economy Lundkvist, and on behalf of the GDR, the Minister of Environment Protection Reichelt. The agreement is an act following resolutions of the Helsinki Security and Cooperation Conference last year.

J.L.

Atmospheric Emissions Atlas

The Atlas of Iron Metallurgy Emissions by S. Jarzębski and J. Kapała has recently been published by "Śląsk" Publishing House in Poland.

The Atlas contains the following subject matters in individual chapters:

Chapter 1 — Examination of the Emissions, which comprises:

— measurements of the parameters of the effluent gas stream,
— measurements of physical properties of dust,
— grain size distribution of dust,
— chemical composition of dust,
— determination of the phase components of dust.

Chapter 2 — How to Use the Information Contained in the Atlas, which comprises:

— ways of determining indices of the atmospheric emissions,
— selection of dust emission control equipment,
— emission abatement by improved manufacturing processes,
— dispersal of emissions,
— utilization of the pollutants arrested.

Moreover, the Atlas contains 151 cards that include results of determination of the quantity and quality of emissions discharged by the iron and ferroalloy metallurgical plants in use in Poland with subdivision into:

— iron ore agglomeration plants,
— blast-furnace process,
— oxygen converter process,
— tandem process,
— open-hearth process,
— electric-arc process,
— electroslag steel remelting process,
— ferroalloy production process.

The authors made use in their study of the available pertinent literature, among others such references as:

— Physical Properties of Dusts, Andrzejewski, R., Gutowski, W.
— Studies on Iron Recovery from Converter Dusts, Anioła J.
— Fundamentals of the X-Ray Diffraction, Cullity, B. D.
— Determination of Toxic Compounds in the Air, Dutkiewicz, T.
— Spectrographic Analysis of Industrial Dusts with the Use of Pouring Technique, Grajpel, A.

J.K.

Improved Working Conditions

In the nationwide competition in the field of improvement of working conditions, thrown open by a number of pertinent agencies and ministeriums (cf. this journal Announcement Section, p. 63) the first prize was awarded to the work entitled An Emission Control Device for Sanding and Polishing. The authors of this prize winner design are L. Mazur, E. Ćwięczek, M. Maciejewski, L. Jenel, and Z. Sipika. This design represents a special-purpose dust collector for the control of gases from local dust-generating sources in manufacturing plants, particularly in working, grinding and polishing of steel, cast-steel, or cast-iron goods, in a wide variety of industries. The device incorporates a wet collector unit of special design provided with a fan. The device is equipped with a control system coupled with the dust-generating machine. Operation of the device enables an adequate trapping of dust-laden air, two-stage cleaning, separation of moisture, and venting of clean air into the environment. Until January 1976 the devices of that type have been acquired by 18 plants. The operating principle and design of the device are described in the leaflet available from the "Kowent" Ventilation and Dust-Collection Equipment Works, Końskie.

J.K.

Air Conservation

Recently in Hungary the results of the fight for conservation of the environment underway for several years have come to be seen, especially those of the struggle for clean air. In the past decade the whole country has been divided into a number of protection zones, and the health resort, recreational areas, as well as nature reserves are under exceptional custody. Somewhat diverse criteria are applied toward congested industrial areas, but also here the air pollution has been greatly abated. For mere air conservation a total of one billion forints had been spent in years 1971 till 1975 in Hungary. Many other activities have been undertaken as well, to name just the training of environment protection specialists at the secondary school and academic levels. Stringent standards have been set up in relation to the provision of newly built industrial projects with necessary air pollution control facilities.

W.Z.

Power Industry and Environment Protection in Poland

The rapid growth of power industry has created a number of problems in relation to the conservation of the natural environment. Particulate emission has been substantially abated. While in 1971 with over 55 million tons of actual coal burned a total of 963 thousand tons of dust was discharged, in 1975 with over 74 million tons of coal used the emission equaled 815 thousand tons of dust. These results were achieved owing to a widespread modernization, reconstruction and construction of new emission control facilities; the expenditures allocated for this purpose in years 1971–1975 attained 1410 million zlotys. In years 1976–1980 an estimated 2251 million zlotys will be spent for this industry. The problem of sulfur dioxide emission is of special concern as it offers substantial difficulties.

W.Z.

A Hot-Gas Pipeline

For the conveyance of hot gases three-layer pipelines are commonly used, but notwithstanding the heat losses are quite considerable. A high-temperature pipeline has been developed by Z. Skibicki of the Institute for Nuclear Research. The advantage of the novel pipeline is minimized heat losses of the gas conveyed. The pipeline in question consists of an inner ceramic pipe made of a refractory material which is cased in an insulating layer.

Prepared after PAP by W.Z.

Shipyard Workers Protect the Environment

The Gdańsk "Lenin" Shipyard expansion project widely accounts for the needs of the environment conservation. The major points are focused on protection against dispersal of various chemical fumes, modernization of sewage system, installation of emission control equipment, and setting up green shelterbelts. A new electroplating and galvanizing facility will adopt advanced technology to abate deleterious effect of its activity on the environment.

Prepared after PAP by W.Z.

Mazout Control

A team of the "Krupska" Textile Plant at Ivanovo, the USSR, designed a simple but efficient filter to arrest mazout in waste water. The design represents a metal structure which accommodates filter material of silicon compounds. The device is installed in the mouth of drain canals 10 to 20 m from the river. As demonstrated by experiment, the filter completely controls the mazout pollution of rivers.

W.Z.

The Air in Japan

Japan has declared war to atmospheric pollution by taking a number of measures to protect natural environment. The budget of the Environment Protection Agency organized in 1971, which in 1975 was allocated for that purpose 10.31% of the total national budget, this year has been raised to 12.51% or to 30.4 billion yen (~101.3 billion dollars). "The philosophy of life of the Japanese" — the local press explains — "always is developing in a symbiosis with nature. Industrial expansion has distributed this harmony which should be restored as soon as possible."

Prepared after PAP by W.Z.

Coal-Fueled Cars

In Great Britain studies are in progress on a turbine-engine for cars to be fueled with pulverized coal. Fluidized combustion of pulverized coal proceeds with a high efficiency that exceeds substantially that in a common furnace. Additionally, "clean" exhausts are produced that contain no toxic components. Experts claim pulverized coal to supersede petroleum-based fuels for cars as the world crude oil resources are depleted.

Prepared after PAP by W.Z.

How to Get Rid of Municipal Refuse

Warsaw Technical University and the Environment Engineering Institute sponsor research work concerned with the problem of municipal refuse. Studies on the Warsaw refuse are aimed at finding the optimum ways for their utilization. With this purpose in mind a special laboratory has been organized (on the premises of the Utilization Department at Radiowo, in the suburbia of Warsaw) which, among other things, investigates the compost produced in the Department. The compost is available for the local gardeners and farmers. The Radiowo Laboratory is the first of this kind in Poland.

Prepared after PAP by W.Z.

A Novel Respirator

In the Patent Office of the Polish People's Republic, a new kind of respirator has been filed under No. 75599. The respirator enables a person

to work safely in the open or indoors in dust-laden atmosphere, with fumes or a high concentration of noxious vapors. The respirator is particularly suitable for unloading of fertilizers, in application of pesticides, feedstuffs compounding, in painting, for work performed inside tanks like tank cleaning or welding. The respirator has no filters, and the overpressure set up around the face does not admit dusts, fumes, vapors or gases to eyes or respiratory ducts, and allows easier breething and protects eyes against dusts.

W.Z.

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